

1996

# Procedural framework for product life cycle assessment using enterprise approach.

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**PROCEDURAL FRAMEWORK FOR PRODUCT LIFE CYCLE  
ASSESSMENT USING ENTERPRISE APPROACH**

**By**

**RAMESH MAJETY**

**A Thesis**

**Submitted to the Faculty of Graduate Studies and Research  
through the Department of Industrial and Manufacturing Systems  
Engineering in Partial Fulfilment of the Requirements for  
the Degree of Master of Applied Science at the  
University of Windsor**

**Windsor, Ontario, Canada**

**1996**

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## **ABSTRACT**

A framework for product life cycle assessment is proposed. The framework attempts to carry out product life cycle assessment using an enterprise approach instead of relying on site specific databases for doing the analysis. The enterprise network consists of different industries at various life cycle stages of the product. Network parameters identified in the thesis are collected for each of the industries in the enterprise network. Demand of the product is forecasted using time series analysis and historical data for earlier demand. The product life cycle inventory analysis is carried out by writing material balance equations. Impact assessment is then carried out by taking global warming potential, gross energy requirement, acidification potential and solid and liquid waste disposal as the impact indicators. All calculations are done for the forecasted demand. A new index, Environment Friendliness Unit (EFU) is defined. This index is used to give a environmental friendliness rating of the product and the industries involved in the enterprise network. Thus it also acts a measure for commitment of the industries to environmental friendly programs.

The proposed framework is used to develop a Computer Software.

**DEDICATION**

***TO MY PARENTS***

***FOR THEIR LOVE AND AFFECTION***

## **ACKNOWLEDGEMENTS**

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## **ABBREVIATIONS**

**Extr** : **Extraction Stage**

**Psg** : **Processing Stage**

**Mfg** : **Manufacturing Stage**

**Utz** : **Utilization Stage**

**Rcy** : **Recycling Stage**

**Disp** : **Disposal Stage**

# **CHAPTER I**

## **INTRODUCTION**

Businesses operating in the 1990s face a variety of competing demands - keeping costs low and quality high, staying competitive in a global marketplace, and meeting consumer preferences for environmentally friendly products. Designing for the environment is a down-to-earth strategy for meeting the demands for environmentally friendly products.

Design for the environment (DFE) is the systematic consideration during the design, of issues associated with the environmental safety and health over the entire life cycle. DFE can be thought of as the shifting of traditional pollution prevention concepts upstream into the development phase of the products before production and use. Building on the concept of Design for the Environment (DFE) pioneered by industry, the Environmental Protection Agency's (EPA of USA) DFE program aims at helping business incorporate environmental considerations into the design and redesign of the products, processes, and technical and management systems.

How does a business “ design for the environment “ ?

A business does so by taking the following measures:

- \* By implementing pollution prevention, energy efficiency, and other resource conservation measures
- \* By making products that can be refurbished, disassembled, and recycled ; and
- \* By keeping careful track of the environmental costs associated with each product or process.

EPA is developing several analytical tools for the business to use in evaluating their processes and products. These include the following :

- \* Cleaner Technology Substitute Assessments (CTSAs) : These assessments help companies compare different technologies or products, with an eye toward selecting the most environmentally friendly alternatives.

- \* Life-Cycle Assessment Tools: EPA is continuing work to a standardised method for comprehensively evaluating the environmental effects of a product, process or activity throughout all stages of its life.

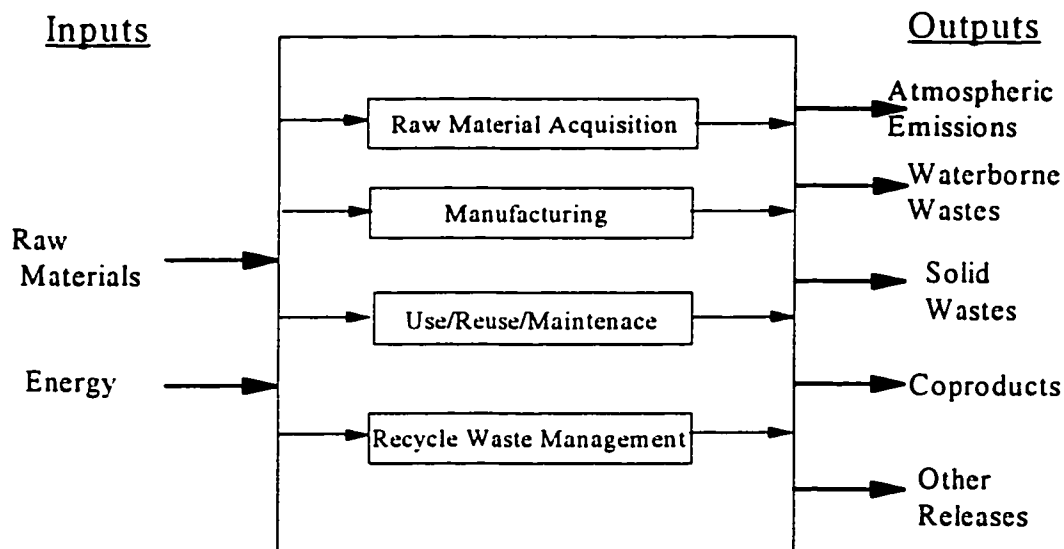
## **1.1 PROBLEM OVERVIEW**

Over the past 20 years, environmental issues have gained greater public recognition. Production, use, and disposal of virtually all goods present potential health and environmental impacts. The general public has become more aware that the consumption of manufacturing products and marketed services, as well as daily activities of our society, adversely affects supplies of natural resources and the quality of the environment. These effects occur at all stages of the Life Cycle of a product (Figure 1), beginning with raw material acquisition and continuing through material manufacture and product fabrication. They also occur during product consumption and a variety of waste management options such as landfilling, incineration, recycling and composting. At each of these steps, pollutants may be released into the environment with ecological consequences. Ecological



consequences among other things also include the effects on the environment. The impacts because of the environment releases can occur during the life cycle stages, particularly manufacturing and disposal, for automobiles, paints, newspapers, cosmetics, television sets, and all other consumer and commercial products. As public concern has increased, both governments and industry have intensified the development and application methods to identify and reduce the adverse environmental effects.

Life Cycle Assessment is rapidly gaining acceptance as a tool that can provide a more precise and realistic view of a product's environmental impacts. According to ISO 14040.2 Draft :



**Figure 1 . Life Cycle Stages**

*LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service throughout its life cycle.*

The environmental performance of companies and their products are subjects of increasing attention. Recognising the potential environmental impacts of the decisions made during the development of products, is the starting point for substantial improvement of the environmental performance. Environmentally conscious product is still a new issue, and how to realise it, is technologically challenging target. To reduce the environmental burden caused by industrial products, design with life cycle analysis will play an important role.

There has been some work done in this area of Product Life Cycle Assessment in the form of development of guidelines and tools. [ Choi, 1994, Vanderburg *et al*, 1994, Sullivan *et al*, 1995] However no standardised methodology has been accepted to date. Much of the LCA tools and techniques developed involve the use of large inventory databases. However databases tend to be site specific. For example product manufacturing in North America may dissimilar conditions to those in Europe and the Far East because of technological differences, commitment to environmental concerns, etc. Also the literature survey indicates that the supplier of materials may be as important as the choice of material itself when it comes to production of environmentally friendly products. The selection of correct databases then becomes an important criterion and usage of databases providing average country wide figures a questionable judgement for accurate analysis. However, the availability of databases is still in evolution stage. Also a way of quantifying the environmental friendliness of the

industries involved in the life cycle of a product may be a step in the direction of assessing their environmental commitments. In view of the above concerns an alternative framework that models the industries in the life cycle stages as an enterprise network and then conducts LCA is explored. The advantages of such a framework would be two folds - Firstly, each of the industries can be rated for their environment friendliness. Secondly, any product that is manufactured by this network of industries can be analysed by the LCA approach. This research focuses on development of a methodology for life cycle assessment of a product using an enterprise approach.

## **1.2 OBJECTIVE**

The objective of this study is to design a Framework that will conduct a Life Cycle Assessment of a Product by using an Enterprise Approach. The framework will assess environmental effects of future demand of the product as against assessment of a single product.

The framework will calculate the following :

- 1) Demand of the product based on past data.
- 2) Life Cycle Inventory Analysis of the predicted product demand.
- 3) Environmental Impact Analysis of the product demand based on chosen impact indicators.
- 4) Environmental Impact Analysis of the Industries involved in the life cycle stages of the product.
- 5) Defining a new Unit for quantifying the environment friendliness of the Product Demand .

6) Using the defined Unit to quantify the environment friendliness of the Industries involved in the life cycle stages of the product .

Calculations will be done using Life Cycle Analysis and Material Flow concepts. The framework will find use in the following ways :

- 1) Life Cycle Analysis of a product and more importantly a comparison of similar products for their environmental compatibility. The dependence of the framework on design of Enterprise Network as against material databases for its calculations will render a more accurate picture of the comparison.
- 2) Quantification of the environment friendliness of the industries which reflects the commitment of the industries towards environmental management issues.
- 3) Quantification of the environment friendliness of the product which reflects on to products commitment to design for environment.

The Framework will be used to develop a computer software for the same purpose.

### **1.3 LIFE CYCLE ASSESSMENT (LCA)**

Concern with these health and environmental issues has lead to the development of tools to evaluate the “cradle-to-grave” impacts of products and the materials from which they are made. LCA is used as a tool for these evaluations.

LCA comprises four components:

- \* Goal definition and scoping, identifying the LCA's purpose and the expected products of the study, and determining the boundaries( what is and is not included in the study) and assumptions based upon the goal definition;
- \* Life-cycle inventory; quantifying the energy and raw material inputs and environment releases associated with each stage of the production;
- \* Impact analysis; identifying the environmental burdens in the inventory stage of an LCA to quantitatively and/or qualitatively characterise their effects on local and global environments. More specifically, the magnitude of the effects on ecological and human health and on resource reserves are determined;
- \* Improvement analysis; evaluating the opportunity to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle. This stage of LCA has received the least attention.

LCA is not a new concept. The energy crisis of the 1970s was the driving force behind inventory studies commissioned by the US Bureau of Mines and the Department of Energy that focused on the energy requirements of major industries. [ISO] As energy concerns faded, and the solid waste crisis intensified these inventories shifted focus to the generation of solid waste and the other emissions associated with industrial processes. While LCA has existed for a number of years, the development and application of the analytical tool are more recent.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 ENVIRONMENT MANAGEMENT ISSUES**

There are many forces that are contributing to the movement for common world-wide environmental management standards, global environmental problems, regulatory differences between nationals, trade agreements, multi-national companies, and consumer demand for environment friendly products are just a few. Consumer demand for environmental friendly products in Europe and more restrictive product laws in some European countries have in some cases amounted to non-tariff trade barriers. U.S. participation in the development of international standards will help to insure that these European markets remain open to exports. Depending upon who's doing the estimating, the environmental regulatory burden on the U.S. gross national product is anywhere from 3% to 8%. [ISO] This places the companies, regardless of industry, at a tremendous disadvantage and is fuelling the current political trend towards deregulation in the U.S. For industry, the adoption of market-driven environmental management standards is an opportunity to justify deregulation and to level the international playing field. The adoption of these standards by the organisations is intended to be voluntary. [McVaugh, 1995] Nonetheless many organisations, regardless of whether they operate or do business internationally, are expected to feel intense commercial pressure to conform.

ISO 14000 standards are being developed by the ISO Technical Committee 207. There are 35 countries, including Canada and the United States, who are members of this committee. There are five primary standards in ISO 14000. Three of the standards, Environmental Management Systems(EMS), Environmental Auditing(EA), and Environmental Performance Evaluation(EPE), are management related, and the Environmental Labelling and Life-Cycle Assessment standards are product related. The EMS Standard consists of specifications for policy, planning, implementation, corrective action, and management review for an environmental management program. The EA Standards are guidelines for audit procedures and auditor qualifications. The EPE Standard provides the direction in the evaluation of systems and determination of performances. The June, 1995 status of LCA related ISO Standards and the expected date of the final standards is [ISO, 1995] :

14040 Life-Cycle Assessment - General Principles & Procedures, available by 1997.

14041 Life-Cycle Inventory Analysis, Working Draft, 1998.

14042 Life-Cycle Impact Assessment, Working Draft, 1998.

14043 Life-Cycle Improvement Assessment, Working Draft, 1998.

### **2.1.1 CANADIAN CORNER**

Environment Canada has been involved with Life Cycle Tools for the past three years by developing information sources, guidance documents and contributing to international methodology through peer reviews and participation in the Society Toxicology & Chemistry (SETAC ) workshops. The life-cycles program's three-pronged approach includes monitoring international policies and

practices, developing life cycle tools and sharing information. [ Ecocycle,1995] Canada's involvement in International Organisation for Standards is co-ordinated through the Canadian Standards Association (CSA) and CSA Canadian Environment council, a multi-stake-holder body with a strong industry presence. A Federal Life-cycle Management Co-ordinating Committee has been established to tap expertise and data within different federal government departments, and to co-ordinate a position on national and international policy in life cycle approaches.

## **2.2 LCA Why Use it ?**

Pollution prevention through Life Cycle Assessment(LCA) is a departure from evaluating waste management options that look mainly at single issues such as recyclability or reduced toxicity. [Curran, 1993]

A primary objective of LCA is to provide a total life cycle "big picture" view of the interactions of a human activity (manufacturing of product) with the environment. Other major goals are to provide greater insight into the overall environmental consequences of human activities, and to provide decisionmakers with a quantitative assessment of the environmental consequences of an activity. Such an assessment permits the identification of opportunities for environmental improvement. It is important to emphasise that the purpose of LCA is to provide an assessment of a product's environmental performance, and not its life cycle cost. [Sullivan and Young, 1995] However, cost is obviously a critical aspect of a product's success. It is best considered with environmental and other performance factors in the Life Cycle Design(LCD) or Design for the Environment (DFE) framework.



Life Cycle Management, involving the use of Life Cycle Assessment technique, enhances profitability by reducing costs, increasing market share, improving strategic positioning or modifying the constraints on the industry's operations. The benefits may be grouped under the following headings: cost reduction programs, R & D activities and External Relations.

Cost Reduction Programs are detailed inventories of costs, energy, material and waste flows to provide an objective basis for improving existing control systems that reduce :

- raw material expenditures
- energy costs and improve efficiencies
- pollution control and waste management costs
- or eliminate environmental exposures ( hazardous waste liabilities )

R & D Activities include product development, technology choice and market research that are streamlined by the inclusion of Life Cycle Assessment. Some typical applications are :

- Design of environmentally sound products
- Choice of Waste management options
- Avoidance of design-induced environmental problems or liabilities
- Optimisation (economic and environmental) of production processes
- Evaluation and help in the selection of new materials or processes

External Relations use Life Cycle Assessment to provide an objective non controversial basis for discussion of and a catalyst for consensus in relations with persons and entities outside of the Company. Life Cycle Assessment is frequently used to :

- Influence environmental policy-making
- Manage public information programs
- Provide sound technical grounds for environmental ecolabelling programs.

With continued research into refining LCA methodology and making the life cycle data more accessible, the assessments have a potential to become a powerful tool to reduce the environmental burdens associated with a product, process or activity. Both the manufacturers and consumers are realising the need to look at cradle-to-grave environmental consequences of the products they make and use respectively. A LCA will not provide all the answers, but used with additional sources of information, such as cost accounting, it contributes much needed information in a comprehensive decision process.

LCA's can require significant labour hours to collect and verify data. Consequently, they are very costly to complete, which limits the number of products that have been studied. Because of high cost, [Curran, 1993 ]100 ( a small fraction) of the consumer and industrial products now available in the market have been evaluated using LCA. However, most of the 100 LCAs that have been performed were privately funded and are generally not available to public. Of the publicly available ones, the majority concern packaging systems, including beverage containers. [ Curran, 1993]

## 2.3 ISSUES RELATED TO LIFE CYCLE STAGES

### 2.3.1 INVENTORY ASSESSMENT

The Inventory consists of a horizontal (input-output) and vertical (life-cycle) analyses. Each stage of the life-cycle receives input of materials and energy and produces which move on subsequent life-cycle phases and emissions (solid, liquid, gaseous). [Brobak *et al*, 1995]

According to Caduff and Zust, Product Systems should be sub-divided into a set of unit processes such that each unit process encompasses the activities of a single operation or group of operations. [Caduff & Zust, 1995] The input of a unit process is structured in terms of material, energy and resources. Material and energy go through various existing unit processes. The desired output of a unit process is the product. In addition to the product by-products and emissions are generated. The term emissions signifies the many types of output released directly into the ecosphere (smoke and heat, for example). Products and by-products undergo existing unit processes.

Many input and output categories may be specified in an in-depth manner. In this way products, by-products and emissions are defined in terms of materials, energy and resources. Input [I] and output [O] may be described in vector form as follows[Caduff & Zust, 1995]:

$$I := \begin{bmatrix} [M] \\ [E] \\ [R] \end{bmatrix} \text{ and } O := \begin{bmatrix} [P] \\ [A] \\ [Em] \end{bmatrix} \text{ with } [P] := \begin{bmatrix} [M] \\ [Eg] \\ [R] \end{bmatrix}, [A] := \begin{bmatrix} [M] \\ [Eg] \\ [R] \end{bmatrix} \text{ and } [Em] := \begin{bmatrix} [M] \\ [E] \\ [R] \end{bmatrix}$$

where M, E and R stand for Material, Energy and Resources, respectively; P and A stand for Product and By-product, respectively; and Em stands for Emissions.

#### **2.3.1.1 Raw Material Acquisition Stage**

The resource requirements and environmental emissions are calculated for all of the processes involved in acquiring raw materials and energy. This analysis involves tracing materials and energy back to their sources.

#### **2.3.1.2 Material Processing Stage**

This step involves converting a raw material into a form that can be used to fabricate a finished product. Material scrap from a subsystem can be reused internally, sold as industrial scrap, or disposed of as solid waste. The inventory account for each option is handled differently.

#### **2.3.1.3 Manufacturing Stage**

Manufacturing converts intermediate materials into products ready for their intended use by customers. Facilities for which data are reported on a plant wide basis will require allocation of the inputs and outputs to the product of interest.

#### **2.3.1.4 Filling/Packaging/Distribution**

This step includes all manufacturing processes and transportation required to fill, package, and distribute a finished product. Energy consumption and environmental releases are caused by transporting the product to retail outlets or to the customers are accounted for in this step of a product's life cycle.

#### **2.3.1.5 Use/Reuse/Maintenance Stage**

This stage includes all of the activities undertaken by the user of the product or service as well as any maintenance that may be performed by the user or obtained elsewhere. Energy requirements and environmental wastes associated with product storage and consumption are included in this stage.

#### **2.3.1.6 Recycle and Disposal**

Recycle/Disposal management is the last stage in a product's life cycle. In open loop recycling, products are recycled into different products. In closed loop recycling, products are recycled again and again into the same product.

### **2.3.2 REUTILIZATION / REPROCESSING / REMANUFACTURING**

Reutilization includes any activity in which the product or package may be reconditioned, maintained, or serviced to extend its useful life. Secondary utilization is considered as the reutilization phase in this thesis.

Reprocessing is the reformation or recycling of a recovered material. Reprocessing involves a series of activities including collection, separation and processing by which products or other materials are recovered in the form of raw materials for the manufacture of new product.

Remanufacturing is an industrial process that restores worn products to a new like condition. This is done by first disassembling the product and cleaning and refurbishing the reusable parts. A new product is then reassembled by mixing the old and new parts.

### **2.3.3 ENERGY INEFFICIENCY IN COMPUTATIONS**

The energy inefficiency of the electricity-generating and delivery system must be considered. Ideally, the multiplier to convert kilowatt-hours (kWh) into megajoules is 3.6. However, the analyst should compute a specific efficiency based on the electrical generation fuel mix actually used. This value is derived by comparing the actual fuels consumed by the electricity-generating industry in the appropriate provincial or national grid to the actual kilowatt-hours of electricity delivered for useful work. The values include boiler inefficiencies and transmission line losses. However, the US EPA gives

a conversion of 11.3 MJ per kWh which may be used in most cases to reflect the actual use of fuel to deliver electricity to the consumer from the national grid. In Canada, a range of 11.6 to 14.9 MJ/kWh is normally considered. [EPA, 1993]

#### 2.3.4 IMPACT ASSESSMENT

Impact Assessment is at this time a poorly developed stage of LCA. Although some impact assessment methods have been advanced as either complete or partial approaches, none has been agreed upon. Nevertheless, an approach to impact analysis, known as “less is better” is typically practised. With this approach, process and product changes are sought that reduce most, if not all, generated wastes and consumed resources.

According to Guinee and Heijungs [1994] impact assessment includes a characterisation step in which the contribution of resource extraction and pollution emissions to impact categories such as resource depletion, global warming, and acidification are quantified and aggregated as far as possible. This is achieved by multiplying extraction's and emissions by a factor and by aggregating the results of these multiplication's into one “effect score” for each impact category :

$$\text{effect score}_{\text{problem type}} = \sum_i \text{equivalency factor}_{i, \text{problem type}} \times \text{emission or extraction}_i \quad (2.1)$$

Approaches to assessing impacts include relating loadings to environmental standards, modelling exposures and effects of the burdens on a site-specific basis, and developing equivalency

factors for burdens within an impact category. In the valuation step of impact assessment, impacts are weighted and compared to one another.

*It is important to recognise that an LCA impact assessment does not necessarily measure actual impacts. Rather, an impact in LCA is generally considered to be a “reasonable anticipation of an effect” or an impact potential. [Sullivan and Young, 1995]* The reason for using impact potentials is that it is typically difficult to measure an effect resulting from the burdens of a particular product.

*As far as Environmental impacts are concerned the choice for a supplier of a given material might be as important as the choice of material itself. [Epelley et al, 1995]* Ecobillan evaluated a particular plastic part of a car made of polypropylene supplied by two sources. The environmental impacts were compared with a reference thermoset part. It was concluded that depending on which supplier was chosen ( different technology, age, and capacity of plant, transport distance), the propylene part might be better or worse than the thermoset one. If the environmental impacts are a concern, the choice of supplier for a given material might be as important as the choice of material itself because of the tremendous discrepancies among environmental impacts of different processes or plants producing the same material.

In the valuation step of impact assessment, impacts are weighted and compared to one another. Further, attaching weighting factors to various potential impacts for comparison purpose is value laden. Because a consensus on the relative importance of different impacts is anticipated to be contentious, a widely accepted valuation methodology is not expected to be adopted in the foreseeable future.



## 2.4 LIFE CYCLE ANALYSIS OF MATERIALS

Industrial materials are a significant and determining factor in the outcome of the LCA of manufactured products, packaging, and buildings. During each of the life cycle stages materials are explicitly or implicitly analysed from an environmental perspective: materials production, product manufacturing as affected by material composition and processing, product use as related to material performance and properties, and products disposal in terms of material processing. *The LCA of products is fundamentally dependent on the LCA of materials. As such both are concurrently and interdependently analysed and assessed according to their environmental characteristics. [Young and Vanderburg, 1994]*

Choi [1994] has developed a screening method for Inventory Analysis for Industrial Materials. This screening method has been developed to identify and assess material characteristics of the product being surveyed throughout the entire life cycle, from acquisition to disposal.

Material selection, which is fundamental to life cycle design, offers many opportunities for reducing environmental impacts throughout a product life cycle. [Keoleian, 1994] In life cycle design, material selection begins by identifying the nature and source of raw materials. Then environmental impacts caused by material acquisition, processing, use, and end-of-life product management are evaluated. Finally, proposed materials are compared to determine the best choices.

Pre-Consultants [SimaPro] have developed analytical tools for carrying out life cycle inventories of product systems. Environmental agencies of the USA and Canada (EPA & CSA) have released documents related to Life Cycle Assessment. Checklists of criteria for performing life cycle inventory have also been released.

The issue of life cycle assessment relies heavily on the development of a strong database for data on energy consumption, material properties etc. Also the consumption patterns and the cost indexes change as per the geography of the place making the choice of reuse of the database at an alternate site, a questionable judgement.

The strengths and weaknesses of LCA as a tool for environmental decision making relate to its broad coverage-across the life cycle and across many environmental issues. These considerations emphasise the necessity to develop clear goals and scope in a study. In any case LCA becomes a powerful mapping tool to identify selected environmental loadings, assist strategic decision making, and improve the environmental performance of a product over its entire life cycle.

## **CHAPTER III**

### **PROPOSED METHODOLOGY**

#### **3.1 AN OVERVIEW**

The following are the salient features of the proposed methodology :

- 1) Forecasting of product demand based on previous 12 months of demand data.
- 2) Designing the Enterprise Network which involves the identification of different industries during the life cycle stages of the product and their respective data like output capacity, different emissions etc.
- 3) Conducting Life Cycle Inventory for the forecasted demand by using the data and the outputs available from feature (1) and (2).
- 4) Impact assessment to estimate the environment friendliness of industries and the product manufactured.

Global Warming Potential, acidification, solid and liquid waste disposal and gross energy requirement are the four factors considered to determine environmental friendliness.

The use of Enterprise approach has two advantages :

- a) Each of the industries can be rated for their environmental friendliness.
- b) Products manufactured by this network of industries can be better analysed by LCA approach.

### **3.2 SYSTEM BOUNDARIES**

The following are the system boundaries considered in formulating the framework :

- 1) Gasoline & electricity are considered for energy consumption during different life cycle stages of the product.
- 2) Solid & liquid wastes are analysed in terms of hazardous & non hazardous wastes and packaging wastes. Since Packaging wastes can ( depending on industry to industry ) be both hazardous and/or non-hazardous, they can also be treated as a part of them without requiring any separate categorization.
- 3) Transportation details are not considered.
- 4) Life cycles of co-products are not considered.

### **3.3 ASSUMPTIONS**

The following assumptions are made in the framework :

- 1) Future demands are governed by historical relationships. Thus forecasts can be made by fitting equations to historical data.
- 2) Each of the industries (nodes) have a capacity ( multiple products in the case of manufacturing and processing) greater than the demand of the product.

- 3) For the different nodes, the operation is assumed to be carried out in multiple processes and it is assumed that input data would be available for each of the processes should a detailed analysis be required.
- 4) Of the entire available material for remanufacturing at each industry, the proportion available to each manufacturing processes is in the same ratio as the percentage of material flowing through it.
- 5) Of the entire available material for reprocessing at each industry, the proportion available to each Processing stage processes is in the same ratio as the percentage of material flowing through it.

### 3.4 NOMENCLATURE

$ABflowPct[K][L]$	:	Percentage Remanufacturable/Reprocessable Material flow from industry K of Stage A to industry L of Stage B
$ACIDXXInd[K]$	:	Acidification Potential of Industry K at Stage XX
$AegY$	:	Total Air Emissions generated ( by mass ) at Stage Y
$AeY$	:	Air Emissions generated for 1 unit o/p at Stage Y
$BlendRatio[K][I]$	:	Percentage of the Total Reprocessable Material available that can be reused at Industry K - Process I
$COXXInd[K]$	:	Total amount of Co-Products output at Stage XX- Industry K
$CPFZZ[K]$	:	Amount of Co-Product produced for 1 unit output of product at life cycle stage ZZ - Industry K
$DMPsgInd[K]$	:	Amount of Degraded material at Processing Stage - Industry K

<b>DMPsgInd[K][I]</b>	<b>:</b>	<b>Amount of Degraded material at Processing Stage, Industry K - Process I</b>
<b>EFUXXInd[K]</b>	<b>:</b>	<b>Environmental Friendliness Unit of Industry K at Stage XX</b>
<b>EY</b>	<b>:</b>	<b>Energy Consumption for 1 unit o/p at Stage Y</b>
<b>FcstDem</b>	<b>:</b>	<b>Forecast Demand</b>
<b>GERXXInd[K]</b>	<b>:</b>	<b>Gross Energy Requirement of Industry K at Stage XX</b>
<b>GWPXXInd[K]</b>	<b>:</b>	<b>Global Warming Potential of Industry K at Stage XX</b>
<b>IPXX</b>	<b>:</b>	<b>Input at Stage XX</b>
<b>IPXXInd[K]</b>	<b>:</b>	<b>Input Material at Stage XX - Industry K</b>
<b>IPXXIndPro[K][I]</b>	<b>:</b>	<b>Input at stage XX, Industry K - Process I</b>
<b>LwgY</b>	<b>:</b>	<b>Total Liquid Waste generated (by mass ) at Stage Y</b>
<b>LwY</b>	<b>:</b>	<b>Liquid Waste generated for 1 unit o/p at Stage Y</b>
<b>matnum</b>	<b>:</b>	<b>Total number of materials in 1 unit of Product</b>
<b>MlfY</b>	<b>:</b>	<b>Material Loss Factor for Stage Y</b>
<b>MIY</b>	<b>:</b>	<b>Material Lost at Stage Y</b>
<b>MrfY</b>	<b>:</b>	<b>Material Retaining Factor for Stage Y</b>
<b>MRMXXInd[K]</b>	<b>:</b>	<b>Material Remanufactured at Stage XX, Industry K</b>
<b>MRMXXIndPro[K][I]</b>	<b>:</b>	<b>Material Remanufactured at Stage XX, Industry K- Process I</b>
<b>MRPXXInd[K]</b>	<b>:</b>	<b>Material Reprocessed at Stage XX, Industry K</b>
<b>MRPXXIndPro[K][I]</b>	<b>:</b>	<b>Material Reprocessed at Stage XX, Industry K - Process I</b>
<b>MRQXXIndPro[K][I]</b>	<b>:</b>	<b>Material Required at Stage XX, Industry K - Process I</b>
<b>OPXX</b>	<b>:</b>	<b>Output at Stage XX</b>

<b>OPXXInd[K]</b>	<b>:</b>	<b>Output Material at Stage XX - Industry K</b>
<b>P_ACID</b>	<b>:</b>	<b>Product's Acidification Potential</b>
<b>P_EFU</b>	<b>:</b>	<b>Product's Environmental Friendliness Unit</b>
<b>P_GER</b>	<b>:</b>	<b>Product's Gross Energy Requirement</b>
<b>P_GWP</b>	<b>:</b>	<b>Product's Global Warming Potential</b>
<b>P_SLWD</b>	<b>:</b>	<b>Product's Solid &amp; Liquid Waste</b>
<b>Pw</b>	<b>:</b>	<b>Product Weight</b>
<b>RMFXXIndPro[K][I]</b>	<b>:</b>	<b>Remanufacturable Factor for life cycle stage XX, Ind K &amp; Process</b> <b>I: denotes the proportion of input that is remanufacturable and the</b> <b>output is sent to manufacturing stage.</b>
<b>RPFXXIndPro[K][I]</b>	<b>:</b>	<b>Reprocessable Factor for life cycle stage XX, Ind K &amp; Process</b> <b>I: denotes the proportion of input that is reprocessable and the</b> <b>output is sent to processing stage.</b>
<b>RPMPsgIndPro[K][I]</b>	<b>:</b>	<b>Total Reprocessable Material at Processing Stage, Industry</b> <b>K - Process I</b>
<b>RufY</b>	<b>:</b>	<b>Reutilisation Factor at Stage Y: denotes the proportion of output of</b> <b>primary utilization that is reusable for secondary utilization.</b>
<b>SLWDXXInd[K]</b>	<b>:</b>	<b>Solid &amp; Liquid Waste generated by Industry K at Stage XX</b>
<b>SwgY</b>	<b>:</b>	<b>Total Solid Waste generated (by mass ) at Stage Y</b>
<b>SwY</b>	<b>:</b>	<b>Solid Waste generated for 1 unit output at Stage Y</b>
<b>TEY</b>	<b>:</b>	<b>Total Energy Consumed at Stage Y</b>

<b>TMrmMfg[K]</b>	<b>:</b>	<b>Total Remanufacturable Material at Manufacturing Stage - Industry K</b>
<b>TMRPPsg[K]</b>	<b>:</b>	<b>Total Reprocessable material at Processing Stage- Industry K</b>
<b>Tmw</b>	<b>:</b>	<b>Total Material Weight</b>
<b>XXPctInd[K]</b>	<b>:</b>	<b>Percentage flow of input/output undergone at Stage XX - Industry K</b>

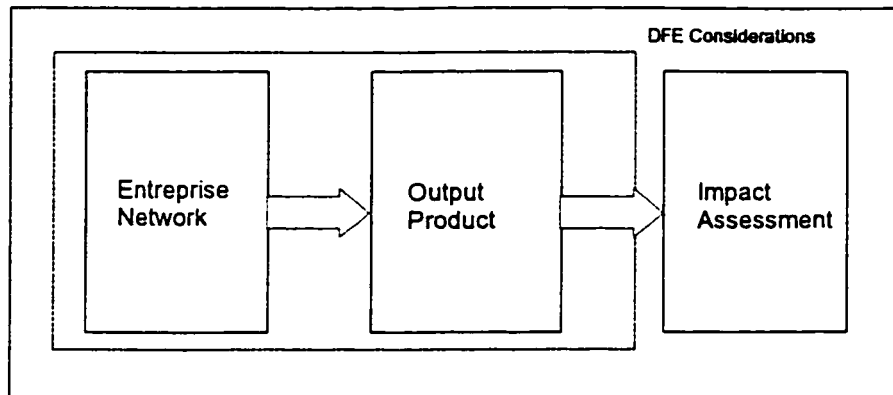
where Y belongs in Utz2 & Utz1

where XX belongs in Utz2, Utz1, Rcy, Mfg, Psg, Extr, K belongs in the number of industries available at each stage, I belongs in the number of processes available at each industry and ZZ belongs in Mfg & Psg only

### **3.5 LAYOUT**

Figure 2 shows the Life Cycle Assessment based on the Enterprise Approach. The Enterprise Network comprises the group of networked industries. The enterprise produces various products. Together, the Output Products and Enterprise Network are assessed for their environmental friendliness by the Impact Assessment technique. Thus the design for environmental evaluation is done for the product as well as the industries manufacturing the product.

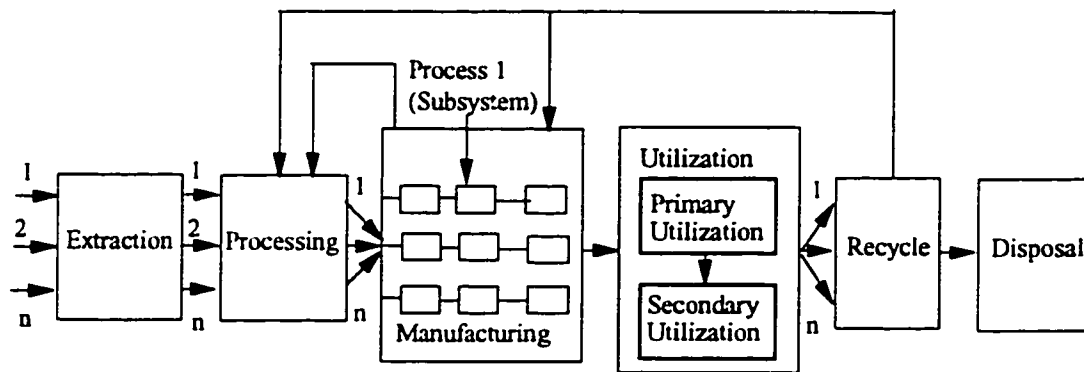




**Figure 2. Life Cycle Assessment based on Enterprise Approach**

### **3.5.1 TIME PERSPECTIVE**

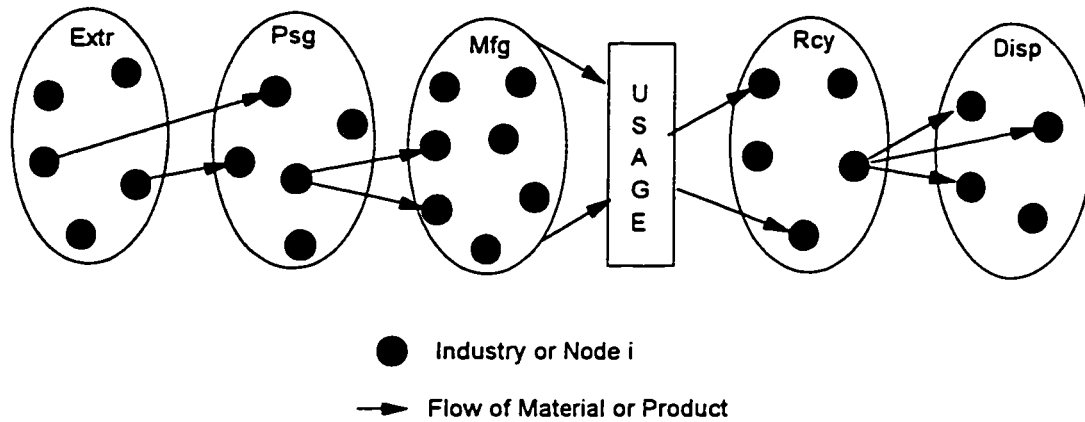
Figure 3 shows the layout of General Life Cycle Stages of a Product. These are the stages of the product from its birth to its death( in a time sense) as it flows through the Enterprise Network. A flow of different raw materials occurs in the extraction and processing stage. At the manufacturing stage the raw materials coalesce to give shape to a product. The product passes through utilisation stage and again disintegrates to material form at the recycling stage.



**Figure 3. Layout of general Life Cycle Stages - A Time Consideration**

### 3.5.2 SPACE CONSIDERATIONS

Figure 4 shows the spatial network of industries involved in the life cycle of product. The reason for spatial consideration is that when the product passes through its different life cycle stages as seen in Figure 3, it is actually passing from one industry to another in the form of material or a component. Two similar products manufactured by different producers, for example, will have a different layout of industries and processes to manufacture the same product. By virtue of this difference the environment friendliness of this similar serving product may be different. Thus taking into account the space considerations helps to accurately quantify the effects of LCA .



**Figure 4. Enterprise Network - A Space Perspective**

### **3.6 DEMAND FORECASTING**

Demand forecasting of the product is done to estimate the amount of waste emissions and energy consumption for the next period. This helps to see the scope of the problem from an Industrial ecology viewpoint as it serves the twin purposes of identifying environment loadings on a larger scale and also of a future demand.

Forecasting can be classified into four basic types - qualitative, time series analysis, casual relationships, and simulation. Qualitative techniques are subjective or judgmental and are based on estimates and opinions. Time series analysis, used in this thesis, assumes that data relating to past demand can be used to predict future demand. Casual forecasting assumes that demand is related to

some underlying factor or factors in the environment. Simulation models allow the forecaster to run through a range of assumptions about the conditions of the forecast.

Regression analysis, exponential weighted moving average and weighted moving average are the three demand forecasting techniques considered in the Time series analysis.

Linear Regression Forecasting is used to fit a line through the data points. The technique is useful when forecasting major occurrences or items such as a product or product line where the demand pattern is consistently increasing or decreasing. The rationale for using regression analysis for forecasting is that the total set of factors that generated the cause system in the past will continue to operate in the future.

The basic equation for a straight line that expresses demand(x) as a function of time(t) is

$$x_t = a + bt \quad \text{where}$$

$$b = \frac{n \sum_{i=1}^n t_i x_i - \sum_{i=1}^n t_i \sum_{i=1}^n x_i}{n \sum_{i=1}^n t_i^2 - \left( \sum_{i=1}^n t_i \right)^2} \quad (3.1)$$

$$a = \bar{x} - b\bar{t}$$

Exponential Weighted Moving Average assigns weights to the demand values of previous periods in inverse proportion to their age. It does this in a very ingenious manner in which only three

pieces of data are required to generate next periods forecast: (1) last period's forecast, (2) last period's actual demand, and (3) a smoothing constant, which determines the relative amount of weight given to recent demand values. The rationale behind exponential weighted moving average is that the forecasting method tracks the demand pattern through its general trends (i.e. "ups and downs") without overreacting to purely random fluctuations. This technique attributes a part of the difference between actual demand and the forecasted demand to a trend shift and the remainder to chance causes.

The generalised procedure is as follows :

$$x_t = ax_{t-1} + (1-a)x_{t-1} \quad (3.2)$$

where a = smoothing constant

Weighted Moving Average generates next period's forecast by averaging the actual demand values for the last n periods with more weight being given to more recent data. The forecasting equation is:

$$x_t = \frac{\sum_{i=1}^n c_i x_{t-i}}{n}$$

where  $c_i$  = weight given to  $i^{th}$  actual value (3.3)

$$\sum_{i=1}^n c_i = n$$

The choice of values for n and the weighting coefficients are arbitrary and can be determined by experimenting with several combinations.

### **3.6.1 CHOICE OF FORECASTING**

Depending on the nature of historic data available to the end user, an appropriate forecasting technique can be used. Alternatively any other equivalent technique can be used to forecast the demand of the product.

## **3.7 INVENTORY ASSESSMENT**

### **3.7.1 ENTERPRISE NETWORK DESIGN**

The entire network of industries that aid in the development product and the recovery of materials after its life are categorised by the Life Cycle Stages namely : Extraction, Processing, Manufacturing and Recycling industries. This way of categorisation helps in clearly outlining the material flow between the group of industries. The following parameters are used to describe each of the industries:

1) Name & Identification

2) Total Material Outputs :                      TOPXXInd[p]                      Tonnes / Yr

3) Total Energy Consumed -

Gasoline :                      GASXXInd[p]                      Mgal / Yr

Electric :	ELECXXInd[p]	Mwh / Yr
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4) Total Air Emissions -

CO <sub>2</sub> :	CO2XXInd[p]	Tonnes / Yr
SO <sub>2</sub> :	SO2XXInd[p]	Tonnes / Yr
NO <sub>x</sub> :	NOXXXInd[p]	Tonnes / Yr
CO :	COXXInd[p]	Tonnes / Yr

5) Total Water Effluents -

Suspended Solid :	SSXXInd[p]	Tonnes / Yr
Hazardous Effluents :	HEXXInd[p]	Tonnes / Yr
Non Hazardous Effluents :	NHEXXInd[p]	Tonnes / Yr

6) Total Solid Waste -

Hazardous Waste :	HWXXInd[p]	Tonnes / Yr
Non Hazardous Waste :	NHWXXInd[p]	Tonnes / Yr
Packaging :	PKGXXInd[p]	Tonnes / Yr

for all XX in Extr, Psg, Mfg, Rcy and all p in each XX.

7) Total Co-Products :	TCOXXInd[p]	Tonnes / Yr
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for XX in Psg & Mfg only and all p in each XX.

Thus XX represents the Life Cycle Stage & p represents the Industry in the life cycle stage.

### **3.7.2 INVENTORY ANALYSIS OF THE PRODUCT**

In this section, a stage by stage Life Cycle Inventory of the forecasted demand of the product is conducted.

#### **3.7.2.1 UTILIZATION ( PRIMARY )**

At this stage, the total material weight for the forecasted demand is calculated by identifying the weight of a single unit of product. The solid, liquid and gaseous emissions together with the energy consumption and output to secondary stage utilization are calculated.

The total material weight of the forecasted demand is

$$Tmw = FcstDem * Pw \quad (3.4)$$

The Material sent for reutilization in the secondary utilization stage is

$$MrUtz2 = RufUtz2 * Tmw / 100 \quad (3.5)$$

The different solid, liquid and air emissions generated at this stage are

$$SwgUtz2 = SwUtz2 * FcstDem \quad (3.6)$$

$$LwgUtz2 = LwUtz2 * FcstDem \quad (3.7)$$

$$AegUtz2 = AeUtz2 * FcstDem \quad (3.8)$$



The total energy consumed during the primary usage phase of the product

$$TE_{Utz2} = E_{Utz2} * F_{cstDem} \quad (3.9)$$

Material outputs and material loss at this stage are

$$OP_{Utz2} = T_{mw} * Mrf_{Utz2} / 100 \quad (3.10)$$

$$MI_{Utz2} = Mlf_{Utz2} * T_{mw} / 100 \quad (3.11)$$

### 3.7.2.2 UTILIZATION ( SECONDARY )

At this stage, output of the secondary utilization stage and overall utilization utage together with the solid, liquid and gaseous emissions are calculated.

$$Mrf_{Utz1} = 100 - Mlf_{Utz1} \quad (3.12)$$

$$IP_{Utz1} = Mru_{Utz2} \quad (3.13)$$

Output of the secondary utilization stage is

$$OP_{Utz1} = IP_{Utz1} * Mrf_{Utz1} / 100 \quad (3.14)$$

Material loss at this stage is

$$MI_{Utz1} = IP_{Utz1} * Mlf_{Utz1} / 100 \quad (3.15)$$

The total output of the utilization stage is

$$OP_{Utz} = OP_{Utz1} + OP_{Utz2} \quad (3.16)$$

The different solid, liquid and air emissions generated at this stage are

$$\text{SwgUtz1} = \text{SwUtz1} * \text{FcstDem} * \text{RufUtz2} / 100 \quad (3.17)$$

$$\text{LwgUtz1} = \text{LwUtz1} * \text{FcstDem} * \text{RufUtz2} / 100 \quad (3.18)$$

$$\text{AegUtz1} = \text{AeUtz1} * \text{FcstDem} * \text{RufUtz2} / 100 \quad (3.19)$$

The total energy consumed during the secondary usage phase of the product

$$\text{TEUtz1} = \text{EUtz2} * \text{FcstDem} * \text{RufUtz2} / 100 \quad (3.20)$$

### 3.7.2.3 RECYCLING

At this stage, Input to the different recycling industries, total remanufacturable material from each industry , total reprocessable material from each industry is calculated.

The Recycling system has RIndN number of industries and each industry carries out recycling of input materials through RProN number of different processes.

$$\text{IPRcy} = \text{OPUtz} \quad (3.21)$$

Input to each of the recycling industries is

$$\text{IPRcyInd}[k] = \text{IPRcy} * \text{RcyPctInd}[k] / 100 ; k = 1 \dots \text{RIndN} \quad (3.22)$$

Input to each of the recycling processes at every industry is

$$\text{IPRcyIndPro}[k][i] = \text{IPRcyInd}[k] * \text{RcyPctIndPro}[k][i] / 100 ; \text{ for each } k, i = 1 \dots \text{RProN} \quad (3.23)$$

The material sent to manufacturing stage (remanufacturable material) through each process at every industry is

$$\text{MRMRcyIndPro}[k][i] = \text{IPRcyIndPro}[k][i] * \text{RmfRcyIndPro}[k][i] / 100 ; \text{ for all } k \text{ \& } i \quad (3.24)$$

The material sent to processing stage (reprocessable material) through each process at every industry is

$$\text{MRPRcyIndPro}[k][i] = \text{IPRcyIndPro}[k][i] * \text{RpfRcyIndPro}[k][i] / 100 ; \text{ for all } k \text{ \& } i \quad (3.25)$$

The total remanufacturable material at every industry is

$$\text{MRMRcyInd}[k] = \sum_{i=1}^{\text{RProN}} \text{MRMRcyIndPro}[k][i] ; \text{ for each } k = 1 \dots \text{RIndN} \quad (3.26)$$

The total reprocessable material at every industry is

$$\text{MRPRcyInd}[k] = \sum_{i=1}^{\text{RProN}} \text{MRPRcyIndPro}[k][i] ; \text{ for each } k = 1 \dots \text{RIndN} \quad (3.27)$$

The concept of Interaction Matrix is introduced to know the amount of remanufacturable/reprocessable material that each of the industries in manufacturing/processing stages receive from other life cycle stage industries.

The interaction matrix for remanufacturable material in Table 1 specifies the percentage of remanufacturable material flow from the recycling industries to manufacturing industries.

MfgInd → RcyInd ↓	1	2	.....MIndN	Total
1	RMflowPct[1][1]	...	...	100 %
2				100 %
3				
.				
.				
.				
RIndN			.....RMflowPct[N][N]	100 %

**Table 1 : Interaction Matrix for Remanufacturable Material at Recycling Stage**

The interaction matrix for reprocessable material in Table 2 specifies the percentage of reprocessable material flow from the recycling industries to processing industries.

PsgInd → RcyInd ↓	1	2	.....PIndN	Total
1	RPflowPct[1][1]	...	...	100 %
2				100 %
3				
.				

RIndN			.....RPflowPct[N][N]	100 %
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**Table 2 : Interaction Matrix for Reprocessable Material at Recycling Stage**

In case of open loop recycling all the elements of interaction matrix are reduced to zero, with the result that no material flows back to the system.

#### **3.7.2.4 MANUFACTURING**

At this stage, co-products manufactured at each industry, material required at each manufacturing process of each industry, input to manufacturing stage and reprocessable material are calculated.

The Manufacturing system has MIndN number of industries and each industry carries out manufacturing of products through MProN number of different processes.

The total output of manufacturing stage is

$$\text{OPMfg} = \text{Tmw} \quad (3.28)$$

Individual outputs from each of the industries is

$$\text{OPMfgInd}[z] = \text{OPMfg} * \text{MfgPctInd}[z] / 100 ; z = 1 \dots \text{MIndN} \quad (3.29)$$

Co-Product output at each of the industries is

$$\text{COMfgInd}[z] = \text{CPFMfg}[z] * \text{OPMfgInd}[z] ; z = 1 \dots \text{MIndN} \quad (3.30)$$

Output from each of the manufacturing industries and through each of the processes is

$$\text{OPMfgIndPro}[z][i] = \text{OPMfgInd}[z] * \text{MfgPctIndPro}[z][i] / 100 ;$$

$$\text{for all } z \text{ \& } i = 1 \dots \text{MProN} \quad (3.31)$$

$$\text{MRQMfgIndPro}[z][i] = \text{OPMfgIndPro}[z][i] / ( \text{MrfMfgIndPro}[z][i] / 100 ) ; \text{for all } z \text{ \& } i \quad (3.32)$$

Total remanufacturable material available at each of the industries is

$$\text{TMrmMfg}[z] = \sum_{k=1}^{\text{RIndN}} \text{MRMRcyInd}[k] * \text{RMflowPct}[k][z] / 100 ; \text{for all } z \quad (3.33)$$

$$\text{IPMfgIndPro}[z][i] = \text{MRQMfgIndPro}[z][i] - ( \text{MfgPctIndPro}[z][i] * \text{TMrmMfg}[z] / 100 ) ; \text{for all } z \text{ \& } i \quad (3.34)$$

Input to each of the manufacturing industry is

$$\text{IPMfgInd}[z] = \sum_{i=1}^{\text{MProN}} \text{IPMfgIndPro}[z][i] ; \text{for all } z \text{ \& } i \quad (3.35)$$

The reprocessable material sent to processing stage through each process at every stage is

$$\text{MRPMfgIndPro}[z][i] = \text{MRQMfgIndPro}[z][i] * ( \text{RpfMfgIndPro}[z][i] / 100 ) ;$$

$$\text{for all } z \text{ \& } i \quad (3.36)$$

The total reprocessable material at every industry is

$$\text{MRPMfgInd}[z] = \sum_{i=1}^{\text{MProN}} \text{MRPMfgIndPro}[z][i]; z = 1 \dots \text{MIndN} \quad (3.37)$$

The interaction matrix for reprocessable material in Table 3 specifies the percentage of reprocessable material flow from the manufacturing industries to processing industries.

PsgInd → MfgInd ↓	1	2	.....PIndN	Total
1	MPflowPct[1][1]	...	...	100 %
2				100 %
3				
.				
.				
.				
MIndN			.....MPflowPct[N][N]	100 %

**Table 3 : Interaction Matrix for Reprocessable Material at Manufacturing Stage**

All the elements of interaction matrix are reduced to zero in case of open loop recycling

### 3.7.2.5 PROCESSING

At this stage, co-products manufactured at each industry, material required at each material processing process of each industry, input to processing stage, reprocessable material and total degraded material are calculated.

The Processing system has PIndN number of industries and each industry carries out processing of raw materials through PProN number of different processes.

The total output of the processing stage is

$$OPP_{sg} = IPM_{fg} \quad (3.38)$$

The output of each of the processing industry is

$$OPP_{sgInd}[x] = OPP_{sg} * P_{sgPctInd}[x] / 100 ; x = 1 \dots PIndN \quad (3.39)$$

Co-Product output of each the industry is

$$COP_{sgInd}[x] = CFP_{sg}[x] * OPP_{sgInd}[x] ; x = 1 \dots PIndN \quad (3.40)$$

Output of each of the processing industries and through every process is

$$OPP_{sgIndPro}[x][i] = OPP_{sgInd}[x] * P_{sgPctIndPro}[x][i] / 100 ; \text{for all } x \text{ \& } i = 1 \dots PIndN \quad (3.41)$$

$$MRQP_{sgIndPro}[x][i] = OPP_{sgIndPro}[x][i] / ( MrfP_{sgIndPro}[x][i] / 100 ) ; \text{for all } x \text{ \& } i \quad (3.42)$$

The total reprocessable material available at each of the industries is



$$\begin{aligned}
\text{TMRPPsg}[x] = & \sum_{k=1}^{\text{RIndN}} \text{MRPRcyInd}[k] * \text{RPflowPct}[k][x] / 100 + \\
& \sum_{z=1}^{\text{MIndN}} \text{MRPMfgInd}[z] * \text{MPflowPct}[z][x] / 100
\end{aligned} \tag{3.43}$$

Amount of reprocessable material used through each of the processes and at every industry

if  $(\text{BlendRatio}[x][i] * \text{MRQPsgIndPro}[x][i] / 100) > (\text{TMRPPsg}[x] * \text{PsgPctIndPro}[x][i] / 100)$  )

then

$\text{RPMPsgIndPro}[x][i] = \text{TMRPPsg}[x] * \text{PsgPctIndPro}[x][i] / 100$       else

$\text{RPMPsgIndPro}[x][i] = \text{BlendRatio}[x][i] * \text{MRQPsgIndPro}[x][i] / 100$  ; for all  $x$  &  $i$       (3.44)

Degraded material generated at each of the industries through every process is

$$\begin{aligned}
\text{DMPsgIndPro}[x][i] = & \text{TMRPPsg}[x] * \text{PsgPctIndPro}[x][i] / 100 - ( \text{BlendRatio}[x][i] * \\
& \text{MRQPsgIndPro}[x][i] / 100 )
\end{aligned} \tag{3.45}$$

$$\text{if } \text{DMPsgIndPro}[x][i] < 0 \quad \text{then} \quad \text{DMPsgIndPro}[x][i] = 0 ; \text{ for all } x \text{ \& } i \tag{3.46}$$

Total input to each process of every industry is

$$\text{IPPsgIndPro}[x][i] = \text{MRQPsgIndPro}[x][i] - ( \text{RPMPsgIndPro}[x][i] ) ; \text{ for all } x \text{ \& } i \tag{3.47}$$

Amount of degraded material generated at each of the processing industries is

$$\text{DMPsgInd}[x] = \sum_{i=1}^{\text{PProN}} \text{DMPsgIndPro}[x][i] \quad (3.48)$$

Input to each of the Processing industries is

$$\text{IPPsgInd}[x] = \sum_{i=1}^{\text{PProN}} \text{IPPsgIndPro}[x][i] \quad (3.49)$$

Total input to processing stage is

$$\text{IPPsg} = \sum_{x=1}^{\text{PIndN}} \text{IPPsgInd}[x] \quad (3.50)$$

### 3.7.2.6 EXTRACTION

At this stage, input to each of the extraction industries and total input to extraction stage is calculated.

The Extraction system has EIndN number of industries and each industry carries out extraction of a different raw material.

The output of the extraction stage is

$$\text{OPExtr} = \text{IPPsg} \quad (3.51)$$

Output at each of the extraction industries is

$$\text{OPExtrInd}[w] = \text{OPExtr} * \text{ExtrPctInd}[w] / 100 ; w = 1 \dots \text{EIndN} \quad (3.52)$$

Input to each of the industries is

$$\text{IPExtrInd}[w] = \text{OPExtrInd}[w] / ( \text{MrfExtrInd}[w] / 100 ) ; w = 1 \dots \text{EIndN} \quad (3.53)$$

Input to the extraction stage is

$$\text{IPExtr} = \sum_{w=1}^{\text{EIndN}} \text{IPExtrInd}[w] \quad (3.54)$$

### 3.7.2.7 DISPOSAL

The Disposal system has DIndN number of disposal sites.

$$\text{IPDisp} = \sum_{\text{XX}} \sum_p \text{SLWDXXInd}[p] + \sum_p \text{DMPsgInd}[p] ; \quad (3.55)$$

for all p & XX in Extr, Psg, Mfg & Rcy

$$\text{IPDispInd}[v] = \text{IPDisp} * \text{PctDispInd}[v] / 100 ; v = 1 \dots \text{DIndN} \quad (3.56)$$

### **3.8 IMPACT ASSESSMENT**

The impact assessment involves utilising the data generated in the inventory phase to analyse and assess the consequences of resource consumption and release of environmental burdens from each of the life cycle stages.

#### **3.8.1 IMPACT INDICATORS CONSIDERED**

Of the various impact indicator categories such as ecosystem health, human health, resource depletion and social health, ecosystem health is the focus of this research.

The following are the four impact indicators considered for assessing ecosystem health :

##### **GLOBAL WARMING POTENTIAL (GWP)**

It is an index calculated from total emissions of greenhouse gases weighted relative to CO<sub>2</sub> in their propensity to contribute to global atmospheric warming. The potential global warming from a quantity of gas emitted to the atmosphere is calculated from the direct radiative forcing of the molecule and the length of time it resides in the atmosphere (Refer Appendix A). Cumulative radiative forcing is integrated over an arbitrary time horizon(100 years is often used). Table 4 presents GWP indexes that are used to convert emissions of greenhouse gases into the GWP currency of CO<sub>2</sub>-equivalent mass [Young and Vanderburg,1994].

Greenhouse Gas	GWP Index
CO <sub>2</sub>	1
CO	2
NO <sub>x</sub>	40
CH <sub>4</sub>	11
CF <sub>4</sub>	4500
C <sub>2</sub> F <sub>6</sub>	> 6200

**Table 4 : GWP Indexes Used to convert Greenhouse Gas Emissions to CO<sub>2</sub> Equivalent Warming**

#### GROSS ENERGY REQUIREMENT (GER)

The GER is defined as the total quantity of energy necessary from the primary energy resources to produce a specified product. The energy requirement does not in itself measure environmental impact, it is however useful as a proxy for the level of stress that energy use may cause in the environment. Table 5 shows the energy profiles for gasoline & electricity [Young and Vanderburg, 1994].

	Electricity	Gasoline
GER Emissions	11.7 MJ/kWh	36 MJ/l
Air Emissions		
CO <sub>2</sub> Emissions	640 g/kWh	2,300 g/l
CO	0.22 g/kWh	19 g/l
HC	1.7 g/kWh	2.4 g/l
NO <sub>x</sub>	2.0 g/kWh	4.8 g/l
Solid Waste Burden	20 g/kWh	2 g/l

**Table 5 : Energy Profiles used in LCA**

#### SOLID AND LIQUID WASTE DISPOSAL (SLWD)

This reflects the contribution to disposal system by the hazardous and non-hazardous solid and liquid wastes.

## **ACIDIFICATION POTENTIAL (ACID)**

Rain, groundwater and surface water bodies are affected by emissions of sulphur dioxide ( $\text{SO}_2$ ), nitrogen oxides ( $\text{NO}_x$ ), and ammonia ( $\text{NH}_3$ ). Acidification may be assessed by acid equivalents (AE), which are calculated as hydrogen ions produced per compound divided by the compound's molecular weight. It can also be assessed by the indicator emissions of  $\text{SO}_2$  and  $\text{NO}_x$ .

$\text{NO}_x$  has been double counted in global warming potential and acidification potential because a compound index has been considered. The idea is not as much to make an accurate numerical evaluation as much as it is to make an anticipation of the effect towards each impact category. However double counting can be avoided if the percentage contribution of the total  $\text{NO}_x$  released, to each impact category is known.

### **3.8.2 DEFINING ENVIRONMENTAL FRIENDLINESS UNIT (EFU)**

EFU unit allows for generation of a single numerical index value for a given product or an industry by taking into account each of the impact indicators. This index value is calculated by taking a weighted average of the quantity of the impacting substances where weights reflect the importance of each of the impact indicators. Because EFU is an index, it has no unit and is a plain numerical value.

EFU in comparison to other environmental impact units takes a top down approach by doing calculations from an industry point of view. Also all the life cycle stage effects are considered towards impact assessment for the four impact categories.

### 3.8.3 ENVIRONMENTAL FRIENDLINESS OF INDUSTRIES

IMPACT ASSESSMENT for the industries is done in terms of selected impact indicators is given by :

#### Gross Energy Requirement (GER)

Using Table 2 the gross energy requirement for the consumption of gasoline and electricity is calculated as :

$$GER_{XXInd[p]} = [ 163.656 \times 10^6 \text{ GAS}_{XXInd[p]} + 11.7 \times 10^3 \text{ ELEC}_{XXInd[p]} ] \text{ MJ/Yr ; for all } XX \text{ \& } p \quad (3.57)$$

#### Solid & Liquid Waste Disposal (SLWD)

Solid wastes generated by the consumption of electricity is also included. Gasoline produced wastes being negligible are ignored.



$$\begin{aligned} \text{SLWDXInd}[p] = & [ \text{SSXXInd}[p] + \text{HEXXInd}[p] + \text{NHEXXInd}[p] + \text{HWXXInd}[p] + \\ & \text{NHWXXInd}[p] + \text{PKGXXInd}[p] + 0.020 \text{ELECXXInd}[p] ] \text{ Tonnes/Yr ; for all XX \& p } \end{aligned} \quad (3.58)$$

For XX in Psg

$$\begin{aligned} \text{SLWDXInd}[p] = & [ \text{SSXXInd}[p] + \text{HEXXInd}[p] + \text{NHEXXInd}[p] + \text{HWXXInd}[p] + \\ & \text{NHWXXInd}[p] + \text{PKGXXInd}[p] + 0.020 \text{ELECXXInd}[p] + \text{DMPsgInd}[p] ] \text{ Tonnes/Yr ;} \\ & \text{for all p} \end{aligned} \quad (3.59)$$

#### Global Warming Potential (GWP)

$$\begin{aligned} \text{GWPXXInd}[p] = & [ 1 \times \{ \text{CO2XXInd}[p] + 0.640 \text{ELECXXInd}[p] + 10455.80 \text{GASXXInd}[p] \} + \\ & 2 \times \{ \text{COXXInd}[p] + 86.37 \text{GASXXInd}[p] \} + 40 \times \{ \text{NOXXXInd}[p] + 21.82 \text{GASXXInd}[p] \} ] \\ & \text{Tonnes/Yr ; for all XX \& p} \end{aligned} \quad (3.60)$$

#### Acidification (ACID)

$$\text{ACIDXXInd}[p] = [ \text{SO2XXInd}[p] + \text{NOXXXInd}[p] ] \text{ Tonnes/Yr ; for all XX \& p} \quad (3.61)$$

where XX represents the life cycle stage systems Extr, Psg, Mfg, Rcy and variable p represents the industries in each of the life cycle stage systems.

ENVIRONMENT FRIENDLINESS is calculated as

$$\text{EFUXXXInd}[p] = \{ W_1 \times \text{GERXXInd}[p] + W_2 \times \text{SLWDXXInd}[p] + W_3 \times \text{GWPXXInd}[p] + W_4 \times \text{ACIDXXInd}[p] \} / 1.0 \quad ; \text{ for all XX \& p} \quad (3.62)$$

where  $W_1, W_2, W_3, W_4$  are the weights associated with each Impact category. A suggested value of the weights are 0.15, 0.25, 0.3 and 0.3 for  $W_1, W_2, W_3$ , and  $W_4$  respectively.

In the calculation of the environmental friendliness, ecosystem health being the primary concern, a high weightage is given to global warming potential and acidification, a lower weightage to solid and liquid waste disposal and minimal weightage to gross energy requirement.

Less the value of EFUXXXInd[p] , More the environment friendliness of the Industry.

#### **3.8.4 ENVIRONMENTAL FRIENDLINESS OF PRODUCT**

IMPACT ASSESSMENT for the Product is done as :

Product Gross Energy Requirement (P\_GER)

The Gross energy consumption of the product (MJ/Period)is :

$$\begin{aligned}
P\_GER = & \sum_{w=1}^{EIndN} \frac{OPExtrInd [w]}{TOPExtrInd [w]} \cdot GERExtrInd [w] + \\
& \sum_{k=1}^{RIndN} \frac{OPRcyInd [k]}{TOPRcyInd [k]} \cdot GERRcyInd [k] + \\
& \sum_{x=1}^{PIndN} \frac{OPPsgInd [x]}{(TOPPsgInd [x] + TCOPsgInd [x])} \cdot GERPsgInd [x] + \\
& \sum_{z=1}^{MIndN} \frac{OPMfgInd [z]}{(TOPMfgInd [z] + TCOMfgInd [z])} \cdot GERMfgInd [z] + \\
& TEUtz1 + TEUtz2
\end{aligned} \tag{3.63}$$

Energy consumption at utilization stages are also taken into account.

#### Product Solid & Liquid Waste Disposal (P\_SLWD) in Tonnes / Period

$$\begin{aligned}
P\_SLWD = & \sum_{w=1}^{EIndN} \frac{OPExtrInd [w]}{TOPExtrInd [w]} \cdot SLWDExtrInd [w] + \\
& \sum_{k=1}^{RIndN} \frac{OPRcyInd [k]}{TOPRcyInd [k]} \cdot SLWDRcyInd [k] + \\
& \sum_{x=1}^{PIndN} \frac{OPPsgInd [x]}{(TOPPsgInd [x] + TCOPsgInd [x])} \cdot SLWDPsgInd [x] + \\
& \sum_{z=1}^{MIndN} \frac{OPMfgInd [z]}{(TOPMfgInd [z] + TCOMfgInd [z])} \cdot SLWDMfgInd [z] + \\
& SwgUt2 + LwgUt2 + SwgUtz1 + LwgUtz1
\end{aligned} \tag{3.64}$$

Product Global Warming Potential (P\_GWP) in Tonnes / Period

$$\begin{aligned}
 P\_GWP = & \sum_{w=1}^{EIndN} \frac{OPExtrInd [w]}{TOPExtrInd [w]} \cdot GWPExtrInd [w] + \\
 & \sum_{k=1}^{RIndN} \frac{OPRcyInd [k]}{TOPRcyInd [k]} \cdot GWPRcyInd [k] + \\
 & \sum_{x=1}^{PIndN} \frac{OPPsgInd [x]}{(TOPPsgInd [x] + TCOPsgInd [x])} \cdot GWPPsgInd [x] + \\
 & \sum_{z=1}^{MIndN} \frac{OPMfgInd [z]}{(TOPMfgInd [z] + TCOMfgInd [z])} \cdot GWPMfgInd [z]
 \end{aligned} \tag{3.65}$$

Product Acidification Potential (P\_ACID) in Tonnes / Period

$$\begin{aligned}
 P\_ACID = & \sum_{w=1}^{EIndN} \frac{OPExtrInd [w]}{TOPExtrInd [w]} \cdot ACIDextrInd [w] + \\
 & \sum_{k=1}^{RIndN} \frac{OPRcyInd [k]}{TOPRcyInd [k]} \cdot ACIDRcyInd [k] + \\
 & \sum_{x=1}^{PIndN} \frac{OPPsgInd [x]}{(TOPPsgInd [x] + TCOPsgInd [x])} \cdot ACIDPsgInd [x] + \\
 & \sum_{z=1}^{MIndN} \frac{OPMfgInd [z]}{(TOPMfgInd [z] + TCOMfgInd [z])} \cdot ACIDMfgInd [z]
 \end{aligned} \tag{3.66}$$

PRODUCT ENVIRONMENT FRIENDLINESS is calculated as :

$$P_{EFU} = \{ W_1 \times P_{GER} + W_2 \times P_{SLWD} + W_3 \times P_{GWP} + W_4 \times P_{ACID} \} / 1 \quad (3.67)$$

where  $W_1, W_2, W_3, W_4$  are the weights associated with each of the impact categories. A suggested value of the weights are 0.15, 0.25, 0.3 and 0.3 for  $W_1, W_2, W_3$ , and  $W_4$  respectively.

Less the value of  $P_{EFU}$ , More the environment friendliness of the Product.

## **CHAPTER IV**

### **PRODUCT LIFE CYCLE ASSESSMENT TOOL TEMPLATE**

#### **4.1 DELPHI**

The computer based tool for product Life Cycle Assessment using enterprise approach has been developed. The proposed methodology in the earlier chapter forms the heart of this computer tool. The development of this tool is done in Delphi.

Delphi is a component-based application development environment supporting rapid development of highly efficient Microsoft windows-based applications with a minimum of coding. Many of the traditional requirements of programming for windows are handled within the Delphi class library, thereby shielding the developer from complicated and mere repetitive programming tasks. Delphi provides design tools such as application and form templates for one to create and test application prototype. Then by using Delphi's rich component set and intuitive code generation, one can turn prototypes into robust applications to fit the business needs. Delphi's database tools enable to develop powerful desktop database and client/server applications and reports.

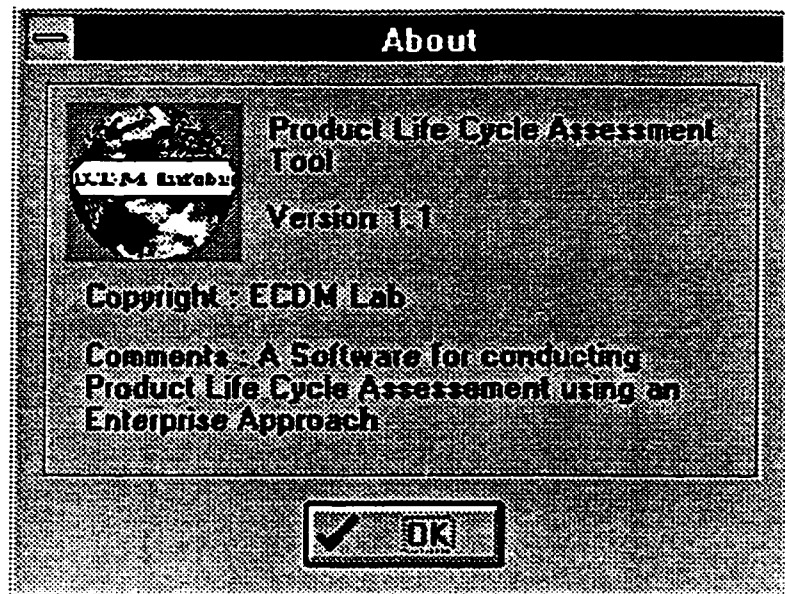
## **4.2 ASSESSMENT SOFTWARE TEMPLATE**

This section presents a broad overview of the tool template developed.

The system design of this assessment tool represents a pseudo client/server architecture with both client and server residing on the same machine. The various data input screens form the clients and the data would be passed on to the main processing program(Main program) forming the server. The processing activity would be done here and the output would be sent to results screen that displays them. Data is available to the “Main” program through user inputs.

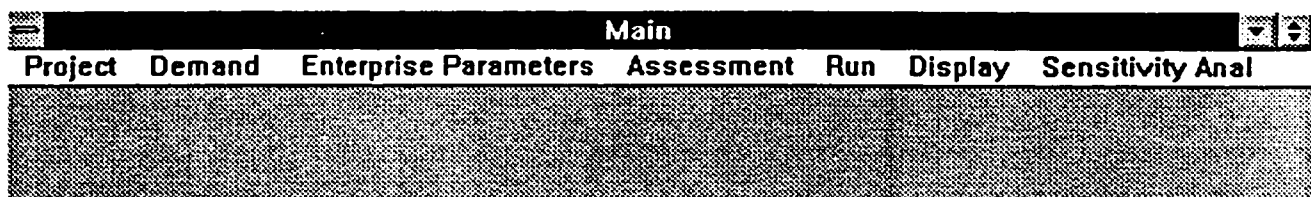
The Application design architecture would be in the following format. In order to have a clear image of the procedure as it is described, pictures of the actual windows of the programs have been included. The software is designed to consider a maximum of 20 industries in the enterprise network design. A standalone executable has been created for the assessment tool which can be run under windows directly.

The program when invoked starts with an About Box which describes about the title of the tool, copyright, version and related comments. Figure 5 Shows the About Box.



**Figure 5. About Box Window of the Program**

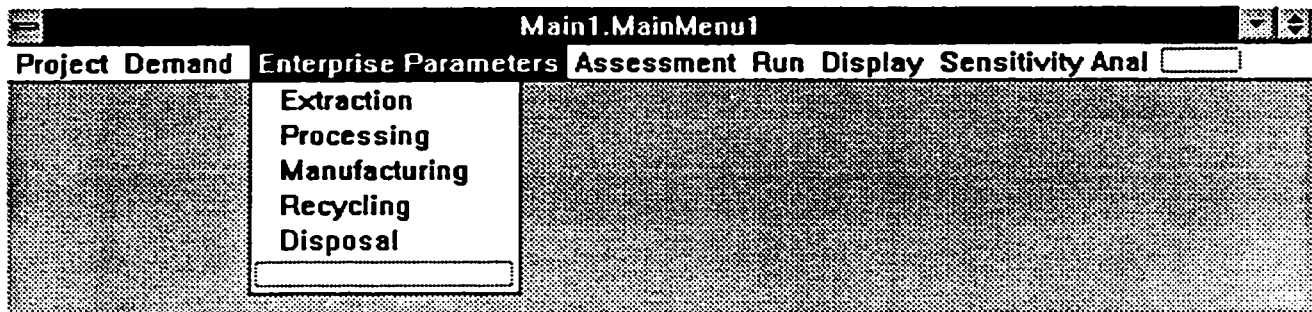
On Clicking the OK button user enters the main menu of the program. Figure 6 shows the Main Menu window of the program. The different functional headings of the software are shown in the main menu. Some of the headings result in a drop to choose further options.



**Figure 6. Main Menu Window of the Program**

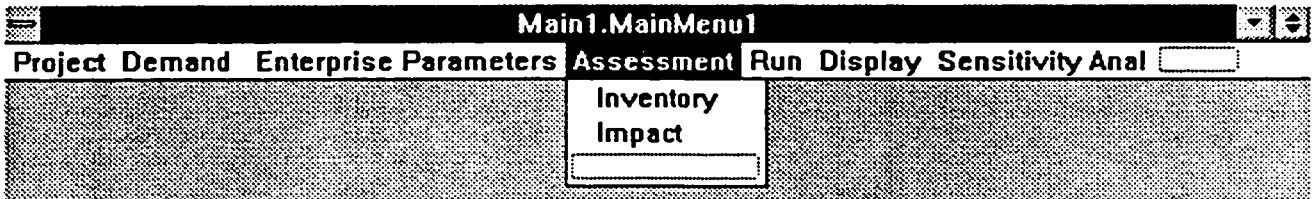


Figures 7, 8, 9 and 10 show the drop boxes of the different headings in the main menu. The network details option in the mainmenu is chosen to enter the network parameters for the different Industries in the different life cycle stages. Each of the life cycle stages has a clickable option as shown in Figure 7.



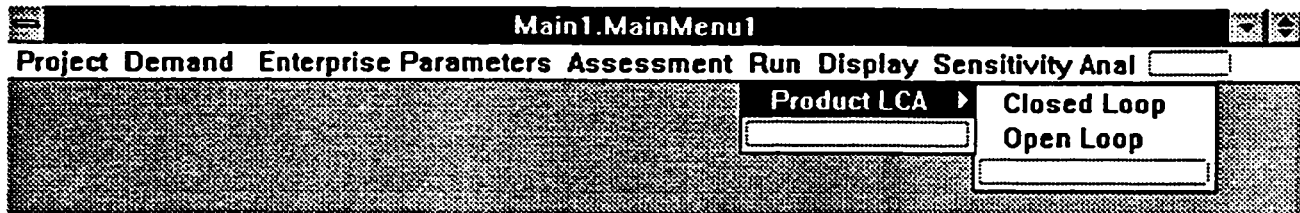
**Figure 7. Main Menu - Network Parameters Window**

Figure 8 shows the inventory details drop box of the main menu. The inventory and impact details are entered through appropriate choice of options. Choosing the inventory option shows the general life cycle stages window of the program.



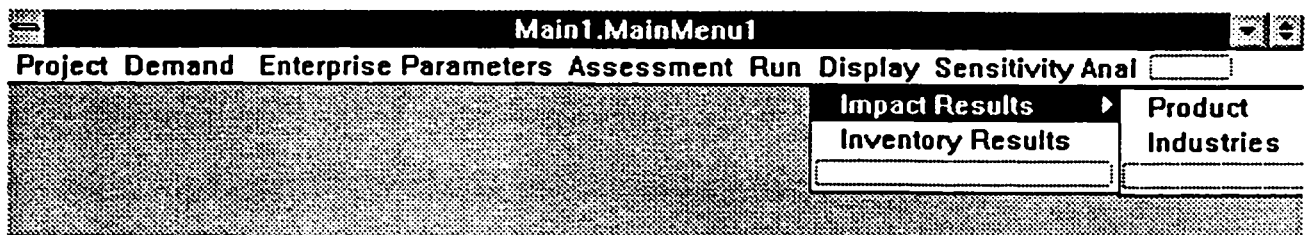
**Figure 8. Main Menu - Inventory Parameters Window**

Figure 9 shows the Run option in the main menu. Two options are available for conducting the product life cycle assessment namely, the closed loop recycling and open loop recycling.



**Figure 9. Main Menu - Run Window of the Program**

Figure 10 shows the display option in the main menu. The Product life cycle assessment results are shown in various screens. Some screens are for showing the impact results and some are for showing the inventory results. The appropriate screens can be invoked by the choice of the right option in the main menu.



**Figure 10. Main Menu - Display Window of the Program**

Figure 11 shows the demand window of the program. Historical data for the previous 12 periods is used to forecast the demand of the next period. Three forecasting techniques are available as options namely - Linear regression, Exponential smoothing and Moving average technique. This screen is invoked by choosing the demand option of the main menu.

**Demand1**

**DEMAND FORECASTING**

Enter the Unit of measurement of the period

Enter the Demand of the Product for the previous 12 periods

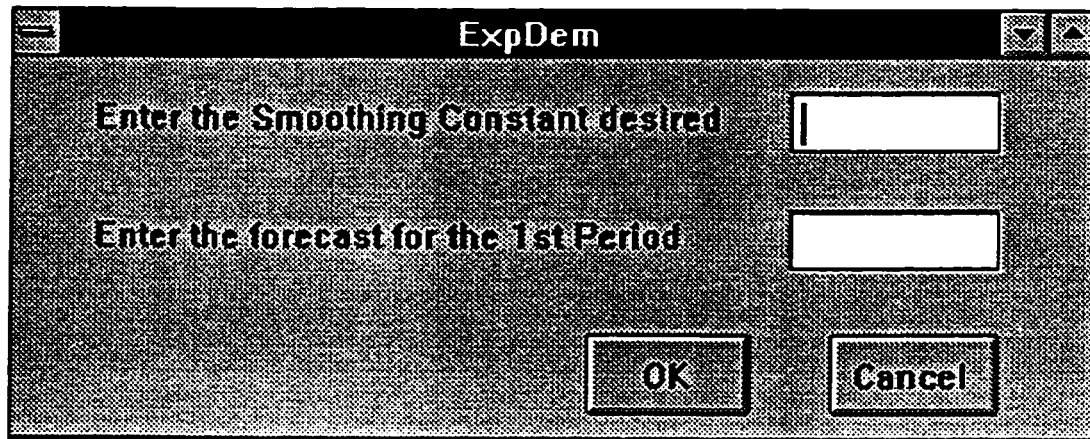
1	<input type="text"/>	2	<input type="text"/>	3	<input type="text"/>
4	<input type="text"/>	5	<input type="text"/>	6	<input type="text"/>
7	<input type="text"/>	8	<input type="text"/>	9	<input type="text"/>
10	<input type="text"/>	11	<input type="text"/>	12	<input type="text"/>

☐ Regression Analysis  
☒ Exponential Weighted Moving Average  
☐ Weighted Moving Average

**Calculate Demand**

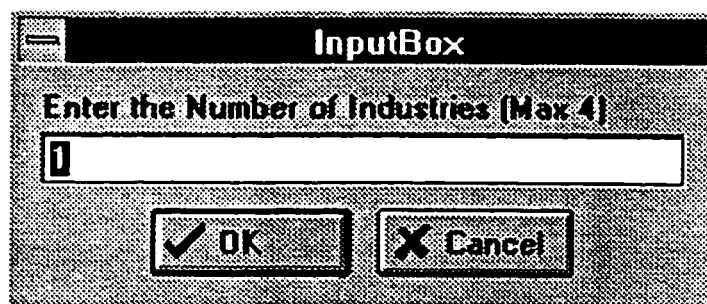
Figure 11. Demand Window of the Program

Figure 12 shows the exponential demand window of the program. This window captures the inputs required for exponential smoothing technique.

A screenshot of a Windows-style dialog box titled "ExpDem". It has a dark gray background and a title bar with standard window controls. The dialog contains two text input fields. The first field is preceded by the text "Enter the Smoothing Constant desired". The second field is preceded by the text "Enter the forecast for the 1st Period". Below the input fields are two buttons: "OK" and "Cancel".

**Figure 12. Exponential Demand Inputs**

Figure 13 & 14 show the input boxes for capturing details regarding the number of industries ( Fig 13) and the number of processes at each of the industries (Fig 14) for each of the life cycle stages. The input boxes show up when the user chooses the life cycle stage in network parameters option of the main menu.

A screenshot of a Windows-style dialog box titled "InputBox". It has a dark gray background and a title bar with standard window controls. The dialog contains a single text input field preceded by the text "Enter the Number of Industries (Max 4)". The input field contains the number "1". Below the input field are two buttons: "OK" with a checkmark icon and "Cancel" with an 'X' icon.

**Figure 13. Input Box I - Network Details**

**InputBox**

Enter # of Processes at each Industry (Max 2)

☒ OK ☐ Cancel

**Figure 14. Input Box II - Network Details**

Figure 15 shows the general screen for capturing the different network parameters for each of the industries in extraction and recycling life cycle stages.

**Network1**

**ENTERPRISE NETWORK DETAILS**

Details for: **Extraction** Industry Number: **1**

Total Material Outputs  Tonnes / Period

Total Energy Consumed

Gasoline  Mgal / Period Electric  Mwh / Period

Total Air Emissions ( In Tonnes / Period )

CO2  SO2

NOx  CO

Total Water Effluents ( In Tonnes / Period )

Suspended Solid  Hazardous Effluents

Non Hazardous Effluents

Total Solid Waste ( In Tonnes / Period )

Hazardous Waste  Non Hazardous Waste

Packaging

**Figure 15. Network Details - Extraction and Recycling Stages**

Figure 16 shows the general screen for capturing the different network parameters for each of the industries in processing and manufacturing life cycle stages. At both of these life cycle stages, co-products are also taken into account.

The screenshot displays a software window titled "Network1". Inside, the header reads "Details for Processing Industry Number 1". The interface contains several input fields for data entry:

- Total Material Outputs**: A single input box followed by the unit "Tonnes / Period".
- Total Energy Consumed**: A label with no input field.
- Gasoline**: An input box followed by "Mgal / Period".
- Electric**: An input box followed by "Mwh / Period".
- Total Air Emissions ( in Tonnes / Period )**: A label with no input field.
- CO2**: An input box.
- SO2**: An input box.
- NOx**: An input box.
- CO**: An input box.
- Total Water Effluents ( in Tonnes / Period )**: A label with no input field.
- Suspended Solid**: An input box.
- Hazardous Effluents**: An input box.
- Non Hazardous Effluents**: An input box.
- Total Solid Waste ( In Tonnes/ Period )**: A label with no input field.
- Hazardous Waste**: An input box.
- Non Hazardous Waste**: An input box.
- Packaging**: An input box.
- Total Co-Product Outputs**: An input box followed by the unit "Tonnes / Period".

**Figure 16. Network Details - Processing and Manufacturing Stages**

Figure 17 shows the general life cycle stages of the product. Invoked from the inventory option of the main menu, this screen serves as the primary screen for capturing the inventory related



parameters for each of the industries at each of the life cycle stages. Fig 18 through 24 would show some of the inventory related parameters captured .

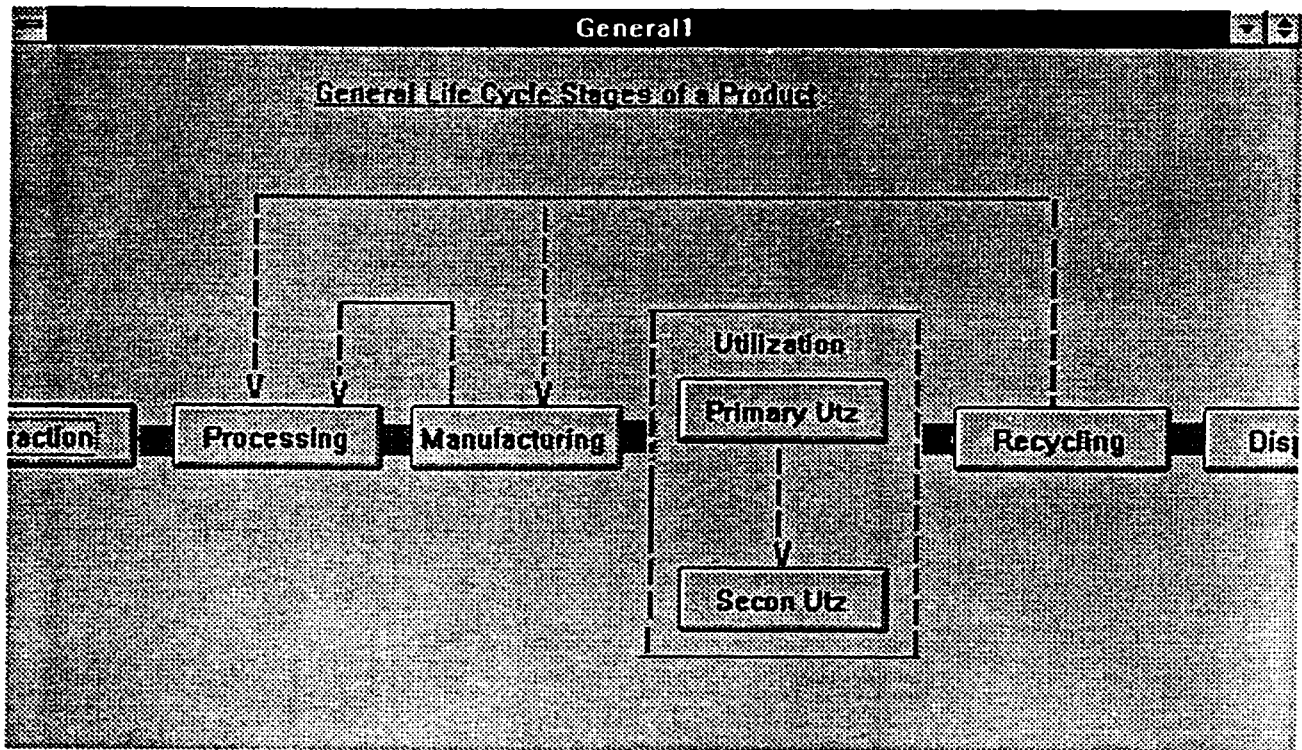


Figure 17. General Life Cycle Stages

Figure 18 captures the percentage flow of material through each of the industries and through each of the processes.

**FlowPct1**

---

**PERCENTAGE OF MATERIAL FLOW THROUGH EACH OF THE  
MANUFACTURING STAGE INDUSTRIES**

---

		1	2	3	4
<input type="checkbox"/> <b>Industry 1</b>	<b>Processes</b>				
<input type="checkbox"/> <b>Industry 2</b>					
<input type="checkbox"/> <b>Industry 3</b>					

**Figure 18. Flow Percentages at different Industries and Processes**

Figure 19 shows the general form for capturing miscellaneous parameters at each of the life cycle stages excluding the processing stage. The miscellaneous parameters pertain to the remanufacturing, material retaining and reprocessible factors at each of the process at that industry and life cycle stage. (Fig 21 shows the screen)



Misc1

**MISCELLANEOUS PARAMETERS FOR THE DIFFERENT LIFE CYCLE STAGES**

**MANUFACTURING STAGE**

**Remanufacturable, Reprocessable and Material Retaining Factors**

<input type="checkbox"/> Industry 1	<input type="checkbox"/> Industry 4
<input type="checkbox"/> Industry 2	<input type="checkbox"/> Industry 5
<input type="checkbox"/> Industry 3	

**Figure 19. Miscellaneous Parameters at different life cycle stages**

Figure 20 shows the screen for capturing miscellaneous parameters at the processing life cycle stage. The miscellaneous parameters pertain to the material retaining and loss factors at each of the process at that industry. Also blending ratio for reprocessing at each of the industries are also captured.

Misc1

**MISCELLANEOUS PARAMETERS FOR THE DIFFERENT LIFE CYCLE STAGES**

**PROCESSING STAGE**

**Remanufacturable, Reprocessable and Material Retaining Factors**

<input type="checkbox"/> Industry 1	<input type="checkbox"/> Industry 4
<input type="checkbox"/> Industry 2	
<input type="checkbox"/> Industry 3	

**Blending Ratio's**

<input type="checkbox"/> Industry 1	<input type="checkbox"/> Industry 4
<input type="checkbox"/> Industry 2	
<input type="checkbox"/> Industry 3	

OK

**Figure 20. Miscellaneous Parameters at Processing Stage**

Figure 21 shows the general screen for capturing the miscellaneous parameters for the various processes at each industry.

Process 1

PROCESS 1

Material Loss Factor (%)

Remanufacturable Factor (%)

Reprocessable Factor (%)

Next OK

Figure 21. Process Details

Figure 22 shows the screen for capturing Interaction matrix parameters at recycling and manufacturing life cycle stages. The interaction matrix captures the percentage flow of reprocessable or remanufacturable material from the current life cycle stage to other life cycle stages.

**Matrix1**

**INTERACTION MATRIX PARAMETERS**

For Remanufacturable Material      At Recycling Stage

MfgInd → RecyInd ↓	1	2	3	4	5	Total
1	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	100 %
2	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	100 %
3	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	100 %
4	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	100 %

**Figure 22. Interaction Matrix Parameters**

Figure 23 captures the primary utilization parameters. Forecasted demand, material retaining factors, energy emissions, waste generations and secondary utilization factors are some of the parameters captures at this stage.

PriUtz1

**PRIMARY UTILIZATION STAGE**

Enter the following parameters of this stage :

The Demand in Units of the Product for the T3 period is	<input type="text"/>	%
Material Retaining Factor (in %)	<input type="text"/>	%
Reutilization Factor (in %)	<input type="text"/>	%
Material Loss Factor (in %)	<input type="text"/>	Kg
Solid Waste generated per unit consumption of product	<input type="text"/>	Kg
Liquid Waste generated per unit consumption of product	<input type="text"/>	Kg
Air Emissions generated per unit of product	<input type="text"/>	Kg
Energy consumed during the life cycle of 1 unit of product	<input type="text"/>	MJ
Enter the weight of 1 unit of product	<input type="text"/>	Kg

**Figure 23. Primary Utilization Screen**

Figure 24 shows the screen for capturing secondary utilization parameters. material loss, energy and waste emissions are some of the factors captured through this form.



**SeconUtz1**

**SECONDARY UTILIZATION STAGE**

Material Loss Factor ( In % )  %

Solid Waste generated per unit consumption of Product  Kg

Liquid Waste generated per unit consumption of Product  Kg

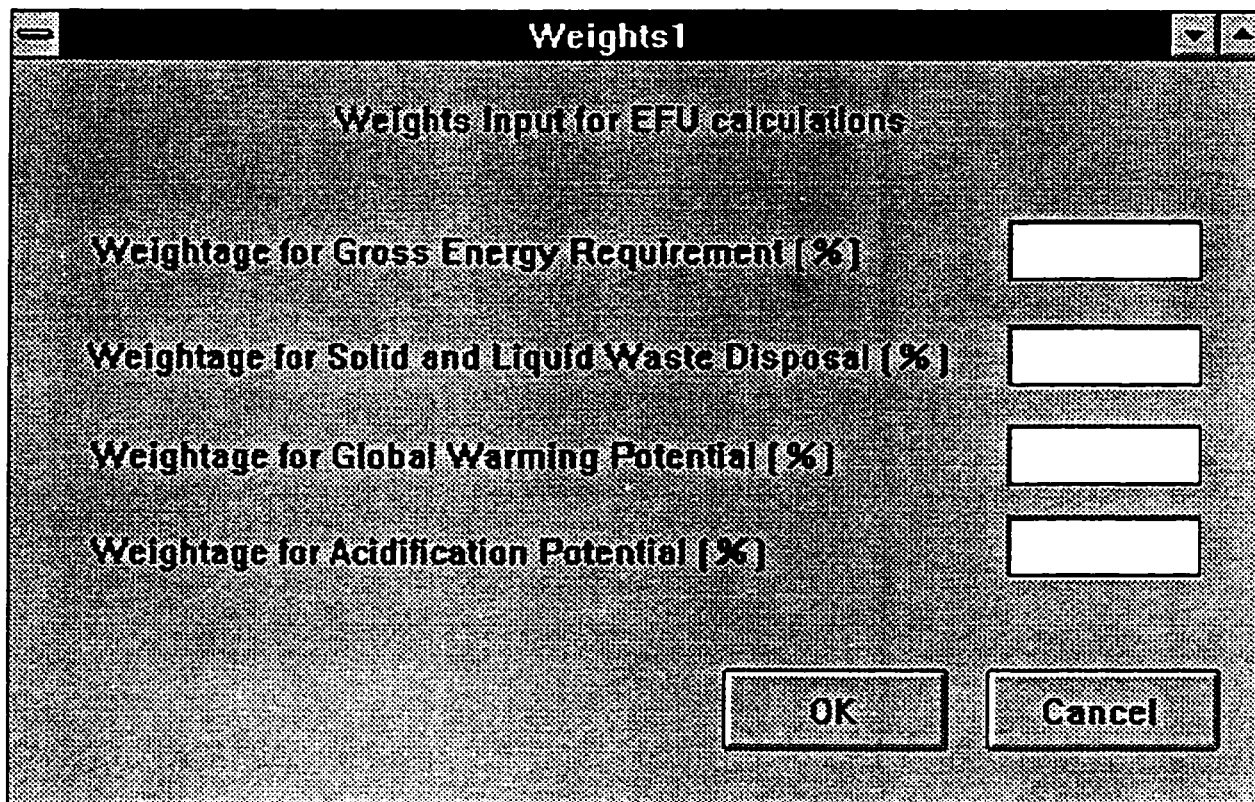
Air Emissions generated per unit consumption of Product  Kg

Energy consumed during the life cycle of 1 unit of Product  MJ

**Figure 24. Secondary Utilization Screen**

Screens shown in figures 18 through 24 are invoked as popup menu options available at each life cycle stage in the general life cycle stage screen.

Figure 25 shows the screen for capturing the risk factors ( weights ) in impact assessment calculations. This screen is invoked from the impact option of the inventory heading of the main menu.



The image shows a software dialog box titled "Weights1". Inside the dialog, the text "Weights Input for EFU calculations" is centered. Below this, there are four rows, each consisting of a text label followed by an empty rectangular input field. The labels are: "Weightage for Gross Energy Requirement [ %]", "Weightage for Solid and Liquid Waste Disposal [ %]", "Weightage for Global Warming Potential [ %]", and "Weightage for Acidification Potential [ %]". At the bottom right of the dialog, there are two buttons: "OK" and "Cancel".

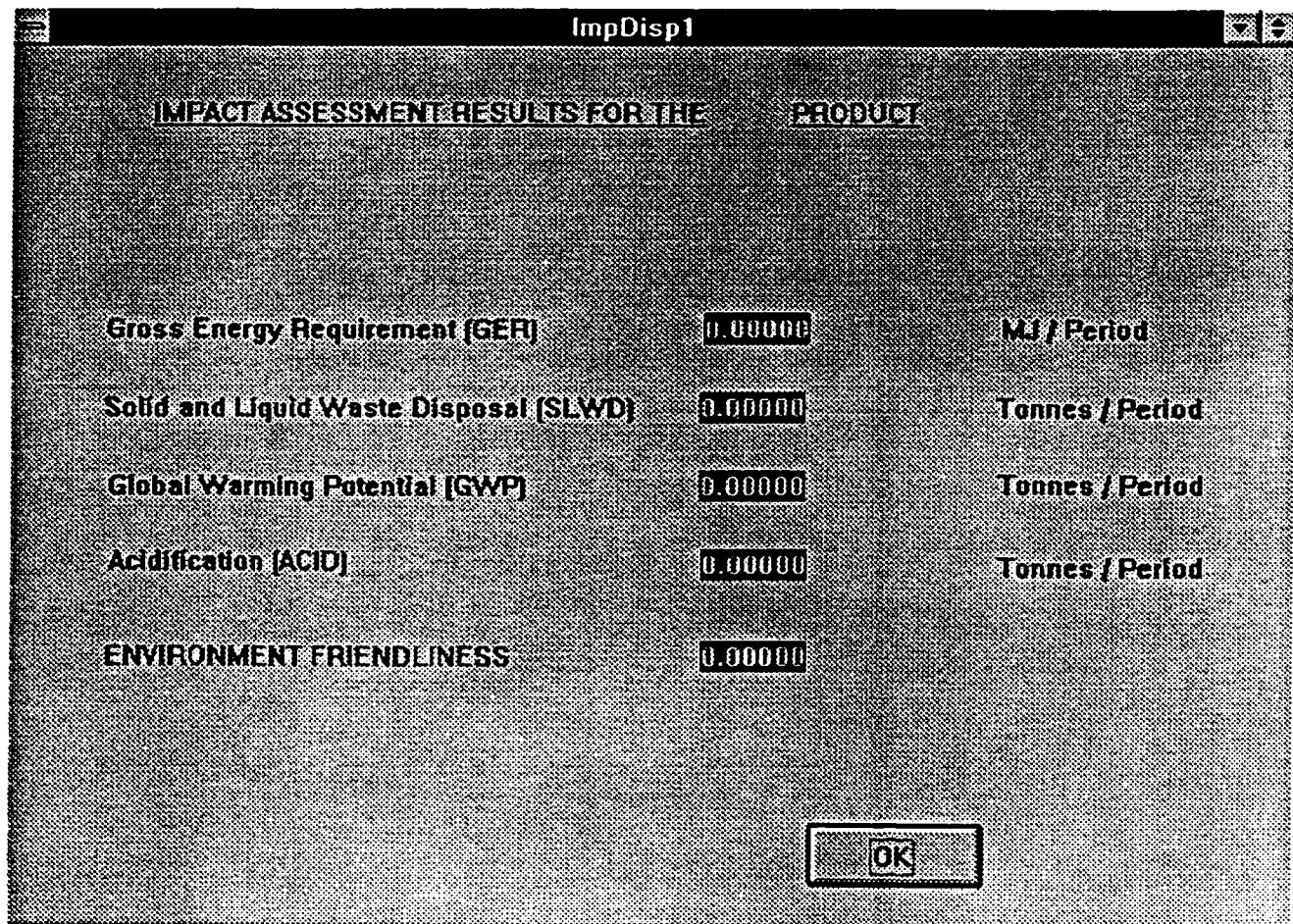
Label	Input Field
Weightage for Gross Energy Requirement [ %]	<input type="text"/>
Weightage for Solid and Liquid Waste Disposal [ %]	<input type="text"/>
Weightage for Global Warming Potential [ %]	<input type="text"/>
Weightage for Acidification Potential [ %]	<input type="text"/>

OK Cancel

**Figure 25. Impact Weights Inputs**

Figure 26 & 27 show the screens for displaying the results of the product life cycle assessment.

Figure 26 shows the impact results of the product on which LCA was conducted.



**Figure 26. Impact Results for the Product**

Figure 27 shows the impact results for the industries involved in LCA.



ImpDisp1

**IMPACT ASSESSMENT RESULTS FOR THE MANUFACTURING INDUSTRIES**

Industry Number 1

Gross Energy Requirement (GER)	0.00000	MJ / Period
Solid and Liquid Waste Disposal (SLWD)	0.00000	Tonnes / Period
Global Warming Potential (GWP)	0.00000	Tonnes / Period
Acidification (ACID)	0.00000	Tonnes / Period
ENVIRONMENT FRIENDLINESS	0.00000	

Next Prev OK

Figure 27. Impact Results for the Industry

Figure 28 shows the inventory assessment results of the product on which LCA was conducted.

Display\_Emissions

LIFE CYCLE INVENTORY RESULTS

PRIMARY UTILIZATION		
Forecasted Demand	0	Units
Solid Waste	0.00000	Kg
Liquid Waste	0.00000	Kg
Air Emissions	0.00000	Kg
Energy Consumed	0.00000	MJ
Material I/P	0.00000	Kg
Material O/P	0.00000	Kg

SECONDARY UTILIZATION		
Solid Waste	0.00000	Kg
Liquid Waste	0.00000	Kg
Air Emissions	0.00000	Kg
Energy Consumed	0.00000	MJ
Material I/P	0.00000	Kg
Material O/P	0.00000	Kg

Figure 28. Inventory Assessment Results I

Figure 29 continues the inventory assessment results of the product on which LCA was conducted.

Display Emissions			
RECYCLING		MANUFACTURING	
Total Remanufacturable		Total Reprocessable	
Material	0.00000 Kg	Material	0.00000 Kg
Total Reprocessable		Material I/P	
Material	0.00000 Kg	Material O/P	0.00000 Kg
Material I/P	0.00000 Kg		
Material O/P	0.00000 Kg		
PROCESSING		EXTRACTION	
Reprocessable Material		Virgin Material Extracted	
Available	0.00000 Kg	( Material I/P )	0.00000 Kg
Degraded Material	0.00000 Kg	Material O/P	0.00000 Kg
Material I/P	0.00000 Kg		
Material O/P	0.00000 Kg		

Figure 29. Inventory Assessment Results II

Figure 30 continues the inventory assessment results of the product on which LCA was conducted.

DISPOSAL		
Solid and Liquid Waste	0.00000	Kg
Degraded Material	0.00000	Kg
Material I/P	0.00000	Kg
		<input type="button" value="Close"/>

Figure 30. Inventory Assessment Results III

Figure 31 shows the screen for carrying out the sensitivity analysis. The interface presents a way to investigate the sensitivity of EFU to its individual weights.

SensAnal1			
SENSITIVITY ANALYSIS			
GER Weight	SLWD Weight	GWP Weight	ACID Weight
<input type="text" value="25"/>	<input type="text" value="25"/>	<input type="text" value="25"/>	<input type="text" value="25"/>
PRODUCT'S EFU RATING		<input type="text" value="0.00000"/>	
			<input type="button" value="Calculate"/>

Figure 31. Sensitivity Analysis

All captured data would eventually be passed on to the main processing program that would conduct life cycle inventory analysis, followed by impact assessment of the product and of the industries producing the product. Finally based on assessment results environment friendliness of the product and the industries will be evaluated.

## **CHAPTER V**

### **AN EXAMPLE DEMONSTRATION**

This chapter demonstrates an example application of the proposed framework. The data is fed on to the Software tool developed for the same purpose and results are obtained. Some of the data is taken from the Environmental Perspective, Studies and Statistics Catalogue of Statistics Canada. [Statistics Canada] Artificial data is taken for other unavailable data. The following are the different data :

#### **5.1 USER INPUT DATA**

##### **5.1.1 Demand Data**

The historical data assumed for previous periods are :

500, 510, 480, 600, 600, 660, 590, 700, 680, 740, 790, 760

Regression analysis technique is used for forecasting the demand.

##### **5.1.2 Enterprise Network**

The enterprise network is defined to have 16 industries. The different industries under each life cycle stage and the respective number of processes are :

Life Cycle Stage	Number of Industries	Number of Processes
Extraction	3	2
Processing	3	3
Manufacturing	4	4
Recycling	3	3
Disposal	3	-

**Table 6 : Network Details**

### 5.1.3 Network Parameters Data

The data for each industry of every life cycle stage are :

#### EXTRACTION STAGE

Parameter	Industry 1	Industry 2	Industry 3
TOPExtr(Tonnes/Yr)	100000	90000	110000
Total Energy Consumed			
GASExtr (Mgal/Yr)	50000	4000	17000
ELECExtr (Mwh/Yr)	10000	7000	11000
Total Air Emissions			

CO <sub>2</sub> Extr (Tonnes/Yr)	65000	50000	70000
SO <sub>2</sub> Extr (Tonnes/Yr)	10000	9000	12000
NO <sub>x</sub> Extr (Tonnes/Yr)	15000	12000	17000
CO Extr (Tonnes/Yr)	35000	30000	37000
Total Water Effluents			
SSE Extr (Tonnes/Yr)	10000	9000	12000
HE Extr (Tonnes/Yr)	1000	900	1100
NHE Extr (Tonnes/Yr)	5000	4500	6000
Total Solid Waste			
HW Extr (Tonnes/Yr)	3000	2500	4000
NHE Extr (Tonnes/Yr)	2000	1800	2500
PKG Extr (Tonnes/Yr)	1000	900	1200

**Table 7 : Network - Extraction Parameters**

PROCESSING STAGE

Parameter	Industry 1	Industry 2	Industry 3
TOPPsg (Tonnes/Yr)	850000	95000	60000
Total Energy Consumed			
GASPsg (Mgal/Yr)	60000	45000	40000
ELECPsg (Mwh/Yr)	30000	35000	20000



Total Air Emissions			
CO <sub>2</sub> Psg (Tonnes/Yr)	70000	75000	50000
SO <sub>2</sub> Psg (Tonnes/Yr)	15000	17000	12000
NO <sub>x</sub> Psg(Tonnes/Yr)	17000	20000	10000
COPsg (Tonnes/Yr)	40000	40000	25000
Total Water Effluents			
SSPsg(Tonnes/Yr)	20000	15000	12000
HEPsg(Tonnes/Yr)	3000	3500	3000
NHEPsg(Tonnes/Yr)	5000	6000	5000
Total Solid Waste			
HWPsg(Tonnes/Yr)	4000	5000	4000
NHEPsg(Tonnes/Yr)	3000	3500	2000
PKGPsg (Tonnes/Yr)	1500	2000	1800
TCOPsg(Tonnes/Yr)	30000	35000	20000

**Table 8 : Network - Processing Parameters**

### MANUFACTURING STAGE

Parameter	Industry 1	Industry 2	Industry 3	Industry 4
TOPMfg(Tonnes/Yr)	700000	65000	75000	90000
Total Energy Consumed				
GASMfg (Mgal/Yr)	55000	50000	35000	30000
ELECMfg (Mwh/Yr)	40000	35000	65000	40000
Total Air Emissions				
CO <sub>2</sub> Mfg (Tonnes/Yr)	45000	40000	50000	35000
SO <sub>2</sub> Mfg (Tonnes/Yr)	12000	10000	15000	17000
NO <sub>x</sub> Mfg(Tonnes/Yr)	7000	6000	9000	10000
COMfg (Tonnes/Yr)	20000	18000	22000	25000
Total Water Effluents				
SSMfg(Tonnes/Yr)	18000	15000	20000	12000
HEMfg(Tonnes/Yr)	2000	1800	1000	1500
NHEMfg(Tonnes/Yr)	3500	3200	3000	2500
Total Solid Waste				
HWMfg(Tonnes/Yr)	3000	2500	2000	1800
NHEMfg(Tonnes/Yr)	2000	2200	1000	1200
PKGMfg (Tonnes/Yr)	6000	5000	5000	6000
TCOMfg(Tonnes/Yr)	10000	15000	10000	15000

**Table 9 : Network - Manufacturing Parameters**

### RECYCLING STAGE

Parameter	Industry 1	Industry 2	Industry 3
TOPRcy(Tonnes/Yr)	30000	25000	40000
Total Energy Consumed			
GASRcy (Mgal/Yr)	10000	7000	14000
ELECRcy (Mwh/Yr)	20000	15000	25000
Total Air Emissions			
CO <sub>2</sub> Rcy (Tonnes/Yr)	10000	9000	9000
SO <sub>2</sub> Rcy (Tonnes/Yr)	12000	11000	11000
NO <sub>x</sub> Rcy(Tonnes/Yr)	9000	8500	8000
CORcy (Tonnes/Yr)	5000	4500	4000
Total Water Effluents			
SSRcy(Tonnes/Yr)	2200	2000	1800
HERcy(Tonnes/Yr)	300	250	500
NHERcy(Tonnes/Yr)	1500	1000	1200
Total Solid Waste			
HWRcy(Tonnes/Yr)	3000	2000	2200
NHERcy(Tonnes/Yr)	1500	1200	1400
PKGRcy (Tonnes/Yr)	500	600	800

**Table 10 : Network - Recycling Parameters**

#### 5.1.4 Flow Percentages

The percentage flow of material through each of the industries (at different life cycle stages) and through the different processes are :

##### EXTRACTION

ExtrPctInd1	= 35 %	ExtrPctInd1Pro[1]	= 40 %	ExtrPctInd1Pro[2]	= 60 %
ExtrPctInd2	= 35 %	ExtrPctInd2Pro[1]	= 30 %	ExtrPctInd2Pro[2]	= 70 %
ExtrPctInd3	= 30 %	ExtrPctInd3Pro[1]	= 50 %	ExtrPctInd3Pro[2]	= 50 %

##### PROCESSING

PsgPctInd1	= 45 %	PsgPctInd1Pro[1]	= 40 %	PsgPctInd1Pro[2]	= 20 %
		PsgPctInd1Pro[3]	= 40 %		
PsgPctInd2	= 20 %	PsgPctInd2Pro[1]	= 30 %	PsgPctInd2Pro[2]	= 30 %
		PsgPctInd2Pro[3]	= 40 %		
PsgPctInd3	= 35 %	PsgPctInd3Pro[1]	= 25 %	PsgPctInd3Pro[2]	= 50 %
		PsgPctInd3Pro[3]	= 25 %		

##### MANUFACTURING

MfgPctInd1	= 30 %	MfgPctInd1Pro[1]	= 25 %	MfgPctInd1Pro[2]	= 25 %
		MfgPctInd1Pro[3]	= 25 %	MfgPctInd1Pro[4]	= 25 %
MfgPctInd2	= 20 %	MfgPctInd2Pro[1]	= 20 %	MfgPctInd2Pro[2]	= 40 %
		MfgPctInd2Pro[3]	= 30 %	MfgPctInd2Pro[4]	= 10 %

MfgPctInd3	= 20 %	MfgPctInd3Pro[1]	= 25 %	MfgPctInd3Pro[2]	= 15 %
		MfgPctInd3Pro[3]	= 25 %	MfgPctInd3Pro[4]	= 35 %
MfgPctInd4	= 30 %	MfgPctInd4Pro[1]	= 40 %	MfgPctInd4Pro[2]	= 10 %
		MfgPctInd4Pro[3]	= 10 %	MfgPctInd4Pro[4]	= 40 %

#### RECYCLING

RcyPctInd1	= 40 %	RcyPctInd1Pro[1]	= 50 %	RcyPctInd1Pro[2]	= 30 %
		RcyPctInd1Pro[3]	= 20 %		
RcyPctInd2	= 40 %	RcyPctInd2Pro[1]	= 45 %	RcyPctInd2Pro[2]	= 25 %
		RcyPctInd2Pro[3]	= 30 %		
RcyPctInd3	= 20 %	RcyPctInd3Pro[1]	= 30 %	RcyPctInd3Pro[2]	= 20 %
		RcyPctInd3Pro[3]	= 50 %		

#### DISPOSAL

DispPctInd1	= 35 %	DispPctInd2	= 45 %	DispPctInd3	= 20 %
-------------	--------	-------------	--------	-------------	--------

### 5.1.5 Miscellaneous Parameters Data

#### EXTRACTION

MrfExtrInd1	= 65 %	MrfExtrInd2	= 55 %	MrfExtrInd3	= 75 %
-------------	--------	-------------	--------	-------------	--------

## PROCESSING

MrfPsgInd1Pro[1] = 65 %   RmfPsgInd1Pro[1] = 15 %   RpfPsgInd1Pro[1] = 20%

MrfPsgInd1Pro[2] = 45 %   RmfPsgInd1Pro[2] = 35 %   RpfPsgInd1Pro[2] = 20%

MrfPsgInd1Pro[3] = 75 %   RmfPsgInd1Pro[3] = 15 %   RpfPsgInd1Pro[3] = 10%

MrfPsgInd2Pro[1] = 50 %   RmfPsgInd2Pro[1] = 25 %   RpfPsgInd2Pro[1] = 70%

MrfPsgInd2Pro[2] = 25 %   RmfPsgInd2Pro[2] = 35 %   RpfPsgInd2Pro[2] = 10%

MrfPsgInd2Pro[3] = 70 %   RmfPsgInd2Pro[3] = 10 %   RpfPsgInd2Pro[3] = 20%

MrfPsgInd3Pro[1] = 85 %   RmfPsgInd3Pro[1] = 10 %   RpfPsgInd3Pro[1] = 5%

MrfPsgInd3Pro[2] = 90 %   RmfPsgInd3Pro[2] = 5 %   RpfPsgInd3Pro[2] = 5%

MrfPsgInd3Pro[3] = 45 %   RmfPsgInd3Pro[3] = 25 %   RpfPsgInd3Pro[3] = 30%

BlendRatioInd1 = 35 %   BlendRatioInd2 = 30 %   BlendRatioInd3 = 40 %

## MANUFACTURING

MrfMfgInd1Pro[1] = 65 %   RpfMfgInd1Pro[1] = 35 %

MrfMfgInd1Pro[2] = 25 %   RpfMfgInd1Pro[2] = 75 %

MrfMfgInd1Pro[3] = 45 %   RpfMfgInd1Pro[3] = 55 %

MrfMfgInd1Pro[4] = 50 %   RpfMfgInd1Pro[4] = 50 %

MrfMfgInd2Pro[1] = 90 %   RpfMfgInd1Pro[1] = 10 %

MrfMfgInd2Pro[2] = 80 %	RpfMfgInd2Pro[2] = 20 %
MrfMfgInd2Pro[3] = 70 %	RpfMfgInd2Pro[3] = 30 %
MrfMfgInd2Pro[4] = 60 %	RpfMfgInd1Pro[4] = 40 %
MrfMfgInd3Pro[1] = 35 %	RpfMfgInd3Pro[1] = 65 %
MrfMfgInd3Pro[2] = 45 %	RpfMfgInd3Pro[2] = 55 %
MrfMfgInd3Pro[3] = 65 %	RpfMfgInd3Pro[3] = 35 %
MrfMfgInd3Pro[4] = 50 %	RpfMfgInd3Pro[4] = 50 %
MrfMfgInd4Pro[1] = 55 %	RpfMfgInd4Pro[1] = 45 %
MrfMfgInd4Pro[2] = 45 %	RpfMfgInd4Pro[2] = 55 %
MrfMfgInd4Pro[3] = 65 %	RpfMfgInd4Pro[3] = 35 %
MrfMfgInd4Pro[4] = 80 %	RpfMfgInd4Pro[4] = 20 %

### RECYCLING

MlfRcyInd1Pro[1] = 10 %	RmfRcyInd1Pro[1] = 45 %	RpfRcyInd1Pro[1] = 45%
MlfRcyInd1Pro[2] = 20 %	RmfRcyInd1Pro[2] = 40 %	RpfRcyInd1Pro[2] = 40%
MlfRcyInd1Pro[3] = 25 %	RmfRcyInd1Pro[3] = 25 %	RpfRcyInd1Pro[3] = 50%
MlfRcyInd2Pro[1] = 5 %	RmfRcyInd2Pro[1] = 45 %	RpfRcyInd2Pro[1] = 50%
MlfRcyInd2Pro[2] = 10 %	RmfRcyInd2Pro[2] = 30 %	RpfRcyInd2Pro[2] = 60%
MlfRcyInd2Pro[3] = 30 %	RmfRcyInd2Pro[3] = 35 %	RpfRcyInd2Pro[3] = 35%

MlfRcyInd3Pro[1] = 25 % RmfRcyInd3Pro[1] = 35 % RpfRcyInd3Pro[1] = 40 %

MlfRcyInd3Pro[2] = 50 % RmfRcyInd3Pro[2] = 35 % RpfRcyInd3Pro[2] = 25 %

MlfRcyInd3Pro[3] = 25 % RmfRcyInd3Pro[3] = 30 % RpfRcyInd3Pro[3] = 35 %

#### 5.1.6 Intercation Matrix Parameters

##### Manufacturing Stage - Reprocessable material

PsgInd → MfgInd ↓	1	2	3	Total
1	30	20	50	100 %
2	25	25	50	100 %
3.	20	20	40	100 %

**Table 11 : Matrix Parameters - Reprocessable Material, Manufacturing Stage**

##### Recycling Stage - Remanufacturable material

MfgInd → RcyInd ↓	1	2	3	4	Total
1	20	20	30	30	100 %
2	25	25	25	25	100 %



3	30	15	25	30	100 %
---	----	----	----	----	-------

**Table 12 : Matrix Parameters - Remanufacturable Material, Recycling Stage**

Recycling Stage - Reprocessable material

PsgInd → RcyInd ↓	1	2	3	Total
1	30	40	30	100 %
2	25	50	25	100 %
3.	45	25	30	100 %

**Table 13 : Matrix Parameters - Reprocessable Material, Recycling Stage**

#### 5.1.7 Primary Utilization

Demand = 812 Units

MrfUtz2 = 65 %      RmfUtz2 = 25 %      MlfUtz2 = 10 %  
 SwgUtz2 = 1000 kg      LwgUtz2 = 3000 kg      AegUtz2 = 700 kg  
 EUtz2 = 1500 MJ      Weight of 1 unit of product = 75 kg

#### 5.1.8 Secondary Utilization

MlfUtz1 = 20 %                      SwgUtz1 = 1200 kg                      LwgUtz1 = 500 kg

AegUtz1 = 1000 kg                      EUtz1 = 1500 MJ

## 5.2 RESULTS

### 5.2.1 IMPACT ASSESSMENT - CLOSED LOOP

#### Impact Assessment for Product ( Run in Closed Loop)

Gross Energy Requirement (MJ / Period)	1.74 E 10
Solid and Liquid Waste Disposal ( Tonnes / Period)	1493.05
Global Warming Potential ( Tonnes / Period )	1225876
Acidification Potential ( Tonnes / Period )	75.78
Environment Friendliness Unit	2.61 E 9

**Table 14 : Product's Impact Assessment**

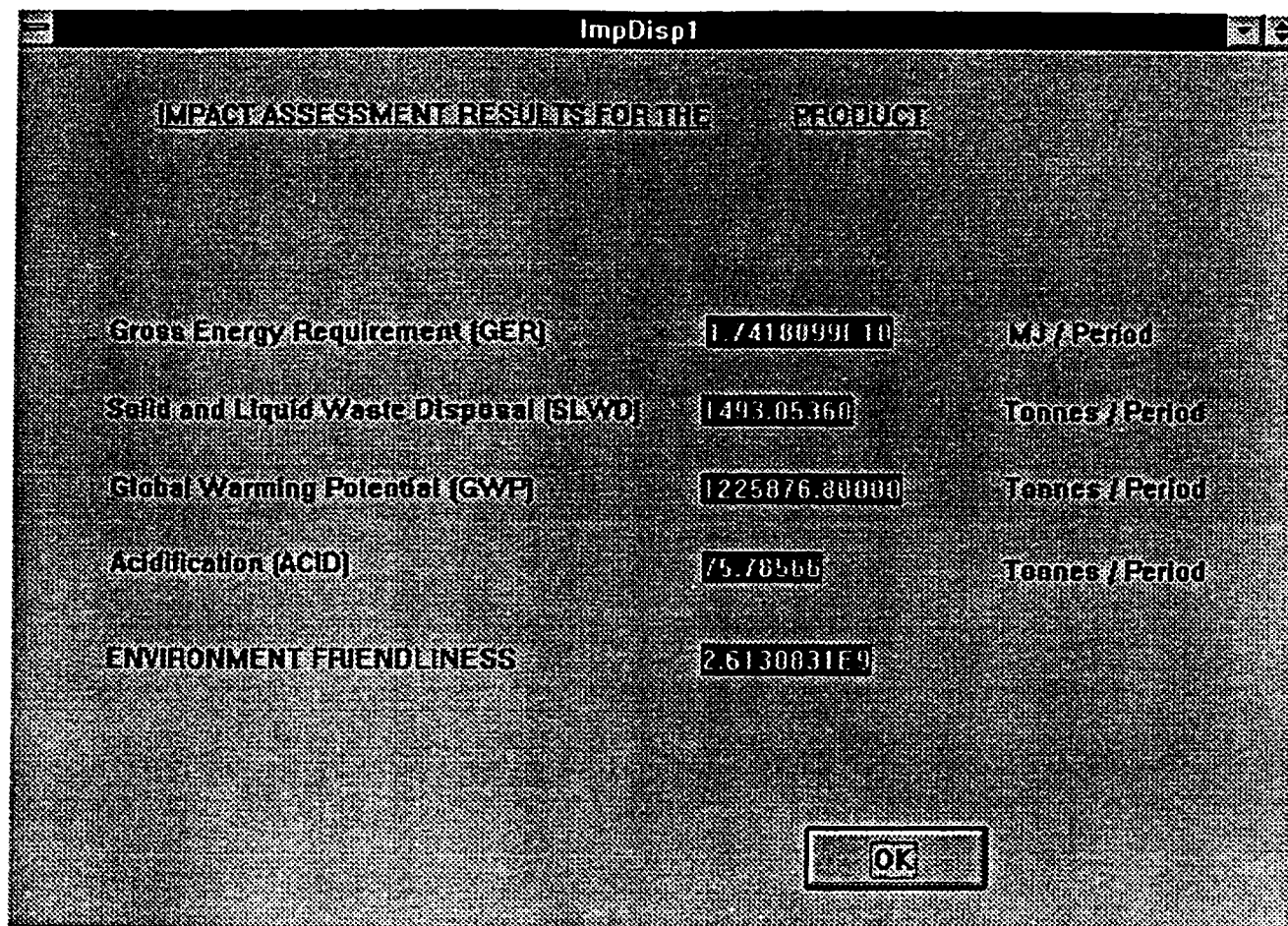


Figure 32. Results - Product Impact Assessment(Closed Loop)

### Impact Assessment for Industries

#### Extraction Stage

Parameter	Industry1	Industry2	Industry3
GER(MJ/Period)	8.18 E 12	6.54 E 11	2.78 E 12
SLWD(Tonnes/Period)	21000	185000	25000

GWP(Tonnes/Period)	5.75 E 8	46599840	1.96 E 8
ACID(Tonnes/Period)	25000	21000.0	29000
EFU	1.22 E 12	9.82 E 10	4.17 E 11

**Table 15 : Industries ( Extraction ) Impact Assessment**

**Processing Stage**

Parameter	Industry1	Industry2	Industry3
GER(MJ/Period)	9.81 E 12	7.36 E 12	6.54 E 12
SLWD(Tonnes/Period)	38500	47136.46	42671.18
GWP(Tonnes/Period)	6.90 E 8	5.18 E 8	4.6 E 8
ACID(Tonnes/Period)	32000	37000	22000
EFU	1.47 E 12	1.10 E 12	9.82 E 11

**Table 16 : Industries ( Processing ) Impact Assessment**

**Manufacturing Stage**

Parameter	Industry1	Industry 2	Industry 3	Industry 4
GER(MJ/Period)	9.0 E 12	8.18 E 12	5.72 E 12	4.91 E 12
SLWD(Tons/Ped)	39500	34200	43000	31200
GWP(Tons/Perd)	6.32 E 8	5.75 E 8	4.03 E 8	3.45 E 8

ACID(Tons/Perd)	19000	16000	24000	27000
EFU	1.35 E 12	1.22 E 12	8.59 E 11	7.36 E 11

**Table 17 : Industries ( Manufacturing ) Impact Assessment**

**Recycling Stage**

Parameter	Industry1	Industry2	Industry3
GER(MJ/Period)	1.63 E 12	1.14 E 12	2.29 E 12
SLWD(Tonnes/Period)	10000	8050	10700
GWP(Tonnes/Period)	1.15 E 8	80876980	1.613 E 8
ACID(Tonnes/Period)	21000	19500	19000
EFU	2.45 E 11	1.71 E 11	3.43 E 11

**Table 18 : Industries ( Recycling ) Impact Assessment**

## 5.2.2 INVENTORY ASSESSMENT - CLOSED LOOP

Inventory Results

**Extraction Stage**

Virgin material extracted = 175039.1 kg

Material output = 111148.3 kg

Material loss = 63890.8 kg

#### Processing Stage

Reprocessible material = 77354.72 kg

Degraded material = 25007.65 kg

Material input = 111148.31 kg

Material output = 97142.96 kg

Material loss = 66352.42 kg

#### Manufacturing Stage

Total reprocessible material = 54992.24 kg

Remanufacturable material = 19670.70

Material input = 97142.96 kg

Material output = 60900.0 kg

Material loss = 920.72 kg

#### Primary Utilization

Forecasted demand = 812 Units

Solid waste = 81200.0 kg

Liquid waste = 243600 kg

Air emissions = 568400 kg

Energy consumed = 1218000 MJ

Material input = 60900 kg

Material output= 39585 kg

Material loss = 6090 kg

#### Secondary Utilization

Solid waste = 243600 kg

Liquid waste = 101500 kg

Air emissions = 203000 kg

Energy consumed = 365400 MJ

Material input = 15225.0 kg

Material output= 12180.0 kg

Material loss = 3045 kg

#### Recycling Stage

Total remanufacturable material = 19670.7 kg

Total reprocessible material = 22362.48 kg

Material input = 51765.0 kg

Material output = 9731.82 kg

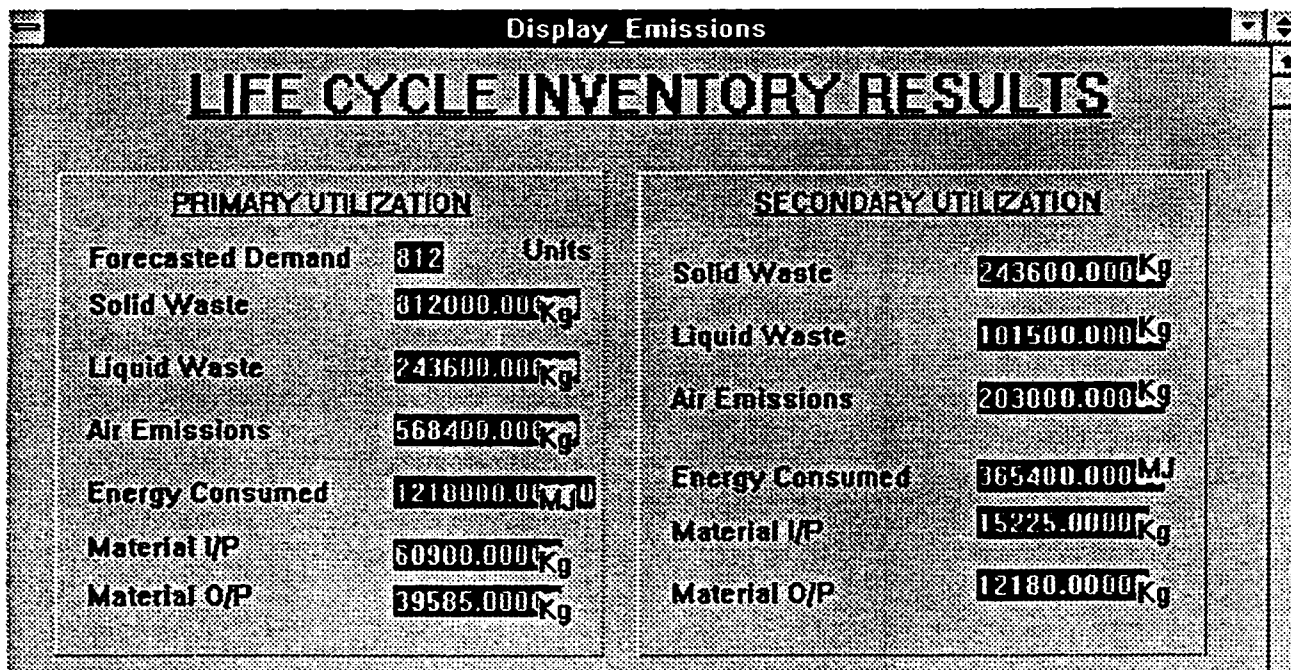
#### Disposal Stage

Solid & liquid waste = 1493.05 kg

Degraded material = 25007.65 kg

**Material input** = 1518061.20 kg

Figures 33, 34 and 35 display the inventory results for the different life cycle stages.



**Figure 33. Results - Inventory Assessment I**



Display_Emissions	
<b>RECYCLING</b> Total Remanufacturable Material <b>19670.700Kg</b> Total Reprocessable Material <b>22362.480Kg</b> Material I/P <b>51765.000Kg</b> Material O/P <b>9731.620Kg</b>	<b>MANUFACTURING</b> Total Reprocessable Material <b>54992.247Kg</b> Material I/P <b>97142.964Kg</b> Material O/P <b>56980.000Kg</b>
<b>PROCESSING</b> Reprocessable Material Available <b>77354.72Kg</b> Degraded Material <b>25007.65Kg</b> Material I/P <b>111148.3Kg</b> Material O/P <b>97142.964Kg</b>	<b>EXTRACTION</b> Virgin Material Extracted (Material I/P) <b>175039.1Kg</b> Material O/P <b>111148.3Kg</b>

Figure 34. Results - Inventory Assessment II

DISPOSAL	
Solid and Liquid Waste	<b>1493.05360Kg</b>
Degraded Material	<b>25007.654Kg</b>
Material I/P	<b>1510061.20Kg</b>
<div>Close</div>	

Figure 35. Results - Inventory Assessment III

### 5.2.3 SENSITIVITY ANALYSIS - CLOSED LOOP

Sensitivity Analysis of Product's EFU to Weights

GER Weight (%)	SLWDWeight(%)	GWP Weight(%)	ACID Weight(%)	EFU
15	25	30	30	2.61 E 9
20	20	30	30	3.48 E 9
10	10	45	35	1.74 E 9
5	5	30	60	8.71 E 8

Table 19 : Sensitivity Analysis

The screenshot shows a software window titled "SensAnal1". Inside the window, the title "SENSITIVITY ANALYSIS" is centered. Below it, there are four input fields labeled "GER Weight", "SLWD Weight", "GWP Weight", and "ACID Weight". The values entered in these fields are 5, 5, 30, and 60 respectively. Below the input fields, the text "PRODUCT'S EFU RATING" is displayed next to the calculated result "8.7127285E8". A "Calculate" button is located at the bottom right of the window.

GER Weight	SLWD Weight	GWP Weight	ACID Weight	PRODUCT'S EFU RATING
5	5	30	60	8.7127285E8

Figure 36. Results - Sensitivity Analysis

#### 5.2.4 IMPACT ASSESSMENT ( OPEN LOOP)

##### Impact Assessment for Product ( Run in Open Loop)

Gross Energy Requirement (MJ / Period)	7.09 E 10
Solid and Liquid Waste Disposal ( Tonnes / Period)	1780.01
Global Warming Potential ( Tonnes / Period )	4992295.8
Acidification Potential ( Tonnes / Period )	342.05
Environment Friendliness Unit	1.06 E 10

**Table 20 : Product's ( Open Loop ) Impact Assessment**

Figure 37 displays the impact assessment results for the open loop case.

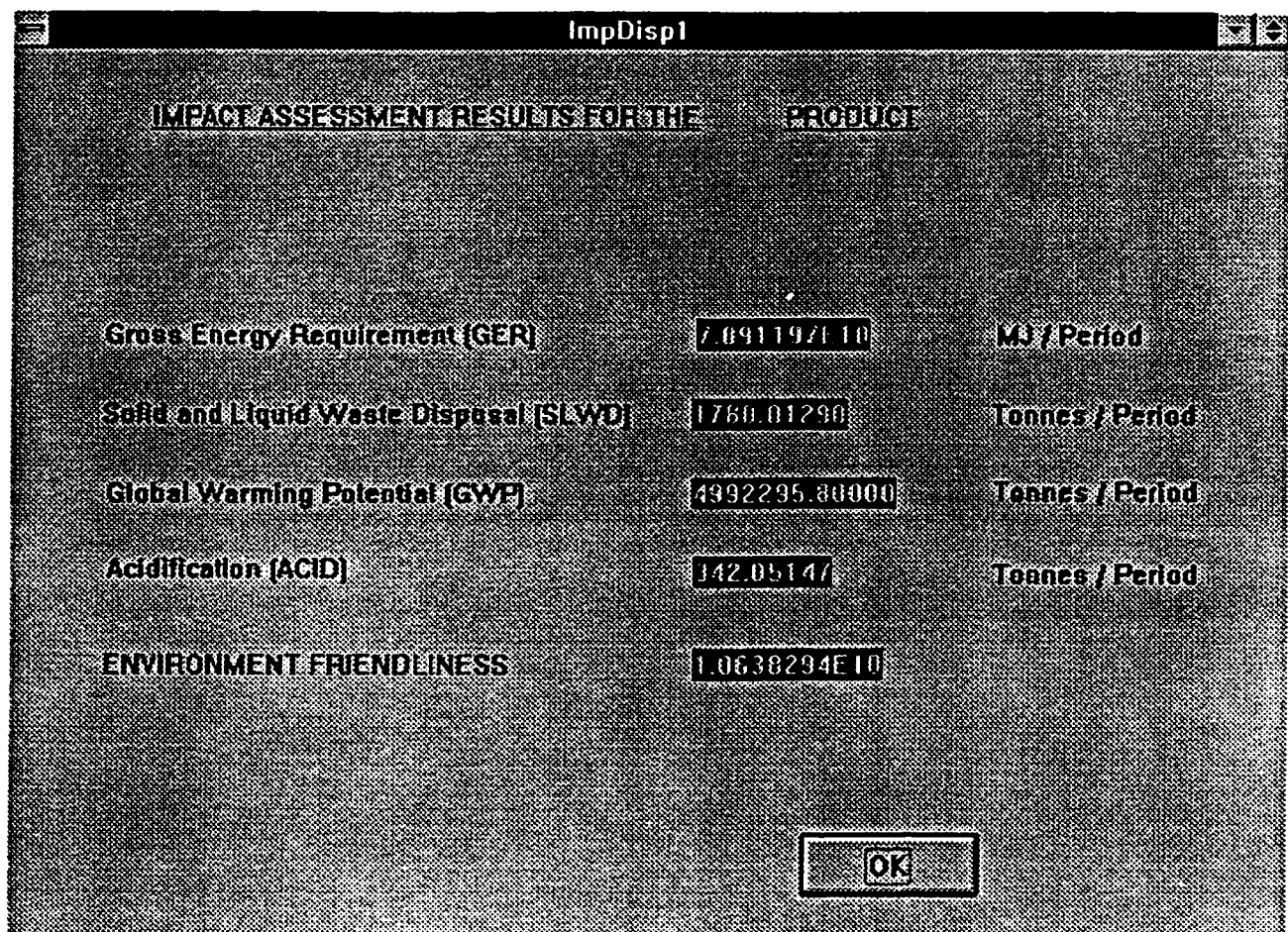


Figure 37. Results - Product Impact Assessment(Open Loop)

### 5.3 DISCUSSION

As seen from the results above the software presents a convenient way of carrying out product life cycle assessment based on the enterprise approach. In the example chosen the product is found to be more environment friendly when recycling of materials is done in a closed loop as against open loop. The commitment of the different industries to environment is also reflected. Which reminds that choice

of the industry ( or manufacturer or supplier) in the development of a product is as important as the choice of the materials making the product. Sensitivity analysis also shows that the environment friendliness of the chosen product in the example is most sensitive to the weight of acidification impact category.

## **CHAPTER VI**

### **CONCLUSIONS**

Environment life-cycle assessment (LCA) of products is a rapidly developing area of applied environmental science. However carrying out LCA studies involve high costs because much of the expenses go in the labour involved in collecting data. EPA is pursuing co-operative efforts with other agencies, industry and appropriate trade associations to perform LCA's and start gathering data in order to demonstrate the feasibility of LCA studies. With the accurate life cycle data availability for different geographical areas still a limitation, this thesis offers a way of carrying inventory assessment from parameters identified in the enterprise network design. Also inclusion of demand as a driving force in the framework helps to study the environment compatibility of a product on a wider scale. The impact assessment technique offers a convenient way of comparing two similar products by a measure of their Environment Friendliness Unit. An EFU rating for the industries attempts to measure the environmental commitment of the enterprise network.

Some of the suggested work that can be done in this direction include :

- 1) Identification of standard benchmarks so that scores are calculated by first evaluating performance in each of the parameters against the benchmarks. Positive and negative 'raw scores' may be awarded for each parameter, depending on how favourably or unfavourably the company's performance compares with the benchmarks. The raw scores can then be weighted based on the

relative importance of the four key parameters. Lastly the weighted scores for all parameters can be added together to give a final score which can be compared to a benchmark score.

- 2) Inclusion of process details at each industry and refining the framework for calculation of impact results.
- 3) Inclusion of Life Cycle Economy(LCE) in the framework as basis for comparison of two similar products. This is essential in order to find the better product in terms of ecology and economy, which are inseparably linked in practice. According to Robert Fenton at the University of Winnipeg, Environmental Economics is a package of tools and concepts to aid decisions about the environment and the economy.
- 4) Addition of sophisticated demand forecasting techniques to more accurately predict the demand.
- 5) Designing the computer tool to consider more than 20 industries for the enterprise network.

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## **APPENDIX A**

### **Nomenclature**

<b>ABflowPct[K][L]</b>	<b>:</b>	<b>Percentage Remanufacturable/Reprocessable Material flow from industry K of Stage A to industry L of Stage B</b>
<b>ACIDXXInd[K]</b>	<b>:</b>	<b>Acidification Potential of Industry K at Stage XX</b>
<b>AegY</b>	<b>:</b>	<b>Total Air Emissions generated ( by mass ) at Stage Y</b>
<b>AeY</b>	<b>:</b>	<b>Air Emissions generated for 1 unit o/p at Stage Y</b>
<b>BlendRatio[K][I]</b>	<b>:</b>	<b>Percentage of the Total Reprocessable Material available that can be reused at Industry K - Process I</b>
<b>COXXInd[K]</b>	<b>:</b>	<b>Total amount of Co-Products output at Stage XX- Industry K</b>
<b>CPFZZ[K]</b>	<b>:</b>	<b>Amount of Co-Product produced for 1 unit output of product at life cycle stage ZZ - Industry K</b>
<b>DMPsgInd[K]</b>	<b>:</b>	<b>Amount of Degraded material at Processing Stage - Industry K</b>
<b>DMPsgInd[K][I]</b>	<b>:</b>	<b>Amount of Degraded material at Processing Stage, Industry K - Process I</b>
<b>EFUXXInd[K]</b>	<b>:</b>	<b>Environmental Friendliness Unit of Industry K at Stage XX</b>
<b>EY</b>	<b>:</b>	<b>Energy Consumption for 1 unit o/p at Stage Y</b>
<b>FcstDem</b>	<b>:</b>	<b>Forecast Demand</b>
<b>GERXXInd[K]</b>	<b>:</b>	<b>Gross Energy Requirement of Industry K at Stage XX</b>
<b>GWPXXInd[K]</b>	<b>:</b>	<b>Global Warming Potential of Industry K at Stage XX</b>
<b>IPXX</b>	<b>:</b>	<b>Input at Stage XX</b>
<b>IPXXInd[K]</b>	<b>:</b>	<b>Input Material at Stage XX - Industry K</b>
<b>IPXXIndPro[K][I]</b>	<b>:</b>	<b>Input at stage XX, Industry K - Process I</b>

<b>LwgY</b>	:	<b>Total Liquid Waste generated (by mass ) at Stage Y</b>
<b>LwY</b>	:	<b>Liquid Waste generated for 1 unit o/p at Stage Y</b>
<b>matnum</b>	:	<b>Total number of materials in 1 unit of Product</b>
<b>MlfY</b>	:	<b>Material Loss Factor for Stage Y</b>
<b>MIY</b>	:	<b>Material Lost at Stage Y</b>
<b>MrfY</b>	:	<b>Material Retaining Factor for Stage Y</b>
<b>MRMXXInd[K]</b>	:	<b>Material Remanufactured at Stage XX, Industry K</b>
<b>MRMXXIndPro[K][I]</b>	:	<b>Material Remanufactured at Stage XX, Industry K- Process I</b>
<b>MRPXXInd[K]</b>	:	<b>Material Reprocessed at Stage XX, Industry K</b>
<b>MRPXXIndPro[K][I]</b>	:	<b>Material Reprocessed at Stage XX, Industry K - Process I</b>
<b>MRQXXIndPro[K][I]</b>	:	<b>Material Required at Stage XX, Industry K - Process I</b>
<b>OPXX</b>	:	<b>Output at Stage XX</b>
<b>OPXXInd[K]</b>	:	<b>Output Material at Stage XX - Industry K</b>
<b>P_ACID</b>	:	<b>Product's Acidification Potential</b>
<b>P_EFU</b>	:	<b>Product's Environmental Friendliness Unit</b>
<b>P_GER</b>	:	<b>Product's Gross Energy Requirement</b>
<b>P_GWP</b>	:	<b>Product's Global Warming Potential</b>
<b>P_SLWD</b>	:	<b>Product's Solid &amp; Liquid Waste</b>
<b>Pw</b>	:	<b>Product Weight</b>
<b>RMFXXIndPro[K][I]</b>	:	<b>Remanufacturable Factor for life cycle stage XX, Ind K &amp; Process I: denotes the proportion of input that is remanufacturable and the output is sent to manufacturing stage.</b>



$RPFXXIndPro[K][I]$	:	Reprocessable Factor for life cycle stage XX, Ind K & Process I: denotes the proportion of input that is reprocessable and the output is sent to processing stage.
$RPMPsgIndPro[K][I]$	:	Total Reprocessable Material at Processing Stage, Industry K - Process I
$RufY$	:	Reutilisation Factor at Stage Y: denotes the proportion of output of primary utilization that is reusable for secondary utilization.
$SLWDXXInd[K]$	:	Solid & Liquid Waste generated by Industry K at Stage XX
$SwgY$	:	Total Solid Waste generated (by mass ) at Stage Y
$SwY$	:	Solid Waste generated for 1 unit output at Stage Y
$TEY$	:	Total Energy Consumed at Stage Y
$TMrMfg[K]$	:	Total Remanufacturable Material at Manufacturing Stage - Industry K
$TMRPsg[K]$	:	Total Reprocessable material at Processing Stage- Industry K
$Tmw$	:	Total Material Weight
$XXPctInd[K]$	:	Percentage flow of input/output undergone at Stage XX - Industry K

where Y belongs in Utz2 & Utz1

where XX belongs in Utz2, Utz1, Rcy, Mfg, Psg, Extr, K belongs in the number of industries available at each stage, I belongs in the number of processes available at each industry and ZZ belongs in Mfg & Psg only

## **APPENDIX B**

### **Global Warming Potential**

Guinee and Heijungs [1994] define Global Warming Potential both on mass basis and volume basis. The first is on a mass basis :

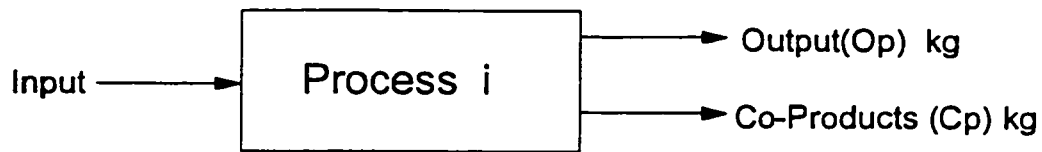
$$\text{GWP}_i (\text{kg. kg}^{-1}) = \frac{\frac{\text{radiative forcing}_i}{m_i (\text{kg})}}{\frac{\text{radiative forcing}_{ref}}{m_{ref} (\text{kg})}}$$

The second is on a volume basis :

$$\begin{aligned} \text{GWP}_i (\text{m}^3. \text{m}^{-3}) &= \frac{\frac{\text{radiative forcing}_i}{V_i (\text{m}^3)}}{\frac{\text{radiative forcing}_{ref}}{V_{ref} (\text{m}^3)}} \\ &= \text{GWP}_i (\text{kg. kg}^{-1}) \times \frac{\rho_i}{\rho_{ref}} \end{aligned}$$

## **APPENDIX C**

### **Co-Product Factor**



**Co-Product Factor (CPF)** : Amount in weight units of the Co-product produced for every unit output of the product.

$$\text{CPF} = \text{Cp} / \text{Op}$$

CPF is used to calculate the amount of Co-products produced at manufacturing and processing stage industries.

## **APPENDIX D**

### **Source Code**

## DEMAND CALCULATIONS

```
procedure TDemand1.Button1Click(Sender: TObject);
var
i: integer;
Demand,FDemand,C : array[1..14] of real;
sigmax,sigmat,sigmatwsq,num,denom,sigmatwsq,b,a : real;
begin

Demand[1] := StrtoFloat(Edit1.Text);
Demand[2] := StrtoFloat(Edit2.Text);
Demand[3] := StrtoFloat(Edit3.Text);
Demand[4] := StrtoFloat(Edit4.Text);
Demand[5] := StrtoFloat(Edit5.Text);
Demand[6] := StrtoFloat(Edit6.Text);
Demand[7] := StrtoFloat(Edit7.Text);
Demand[8] := StrtoFloat(Edit8.Text);
Demand[9] := StrtoFloat(Edit9.Text);
Demand[10] := StrtoFloat(Edit10.Text);
Demand[11] := StrtoFloat(Edit11.Text);
Demand[12] := StrtoFloat(Edit12.Text);
Demand[13] := 0; Demand[14] := 0;
C[12] := 3; C[11] := 2.5; C[10] := 2; C[9] := 1.5;
C[8] := 0.8; C[7] := 0.7; C[6] := 0.5; C[5] := 0.4;
C[4] := 0.3; C[3] := 0.2; C[2] := 0.05; C[1] := 0.05;
FcstDem := 0;

{ Weighted Moving average Method }
if RadioButton3.Checked = True
then
begin
For i := 1 to 12 do
begin
Demand[13] := Demand[13] + Demand[i]*C[i];
end;
Demand[14] := Demand[13]/12;
Label18.Caption := FloattoStrF(Demand[14],ffFixed,8,0);
end;

{ Exponential Weighted Moving Average }
if RadioButton2.Checked = True
then
begin
FDemand[1] := fcsterr;
for i:= 2 to 13 do
begin
FDemand[i] := smthcnst*Demand[i-1] + (1-smthcnst)*FDemand[i-1];
Demand[14] := FDemand[13];
Label18.Caption := FloattoStrF(Demand[14],ffFixed,8,0);
end;
end;

{ Regression Analysis }
if RadioButton1.Checked = True
then
begin
```

```

Demand[13] := 0;
For i := 1 to 12 do
begin
Demand[13] := Demand[13] + i*Demand[i];
end;

sigmax := 0;
For i := 1 to 12 do
begin
sigmax := sigmax + Demand[i];
end;

sigmat := 0;
for i := 1 to 12 do
begin
sigmat := sigmat + i;
end;

num := 12*Demand[13] - sigmat*sigmax;
sigmatwhsq := Sqr(sigmat);

Sigmatsq := 0;
For i := 1 to 12 do
begin
sigmatsq := sigmatsq + Sqr(i);
end;

denom := 12*sigmatsq - sigmatwhsq;

b := num/denom;
a := sigmax/12 - b*sigmat/12;
Demand[14] := a + b*13;
Label18.Caption := FloattoStrF(Demand[14],ffFixed,8,0);
end;

end;

procedure TDemand1.CheckBox1Click(Sender: TObject);
begin
FcstDem := StrToFloat(Label18.Caption);
end;
end.

```

## **ENTERPRISE LIFE CYCLE ASSESSMENT CALCULATIONS**

{ General Variables }

```

IndFlag, ClearFlag, counter, endcounter, DispFlag, MatrixFlag, PushRG, I, J,
K, Ind, Loop: Integer ;
InputString : String ;
FcstDem, Weight1, Weight2, Weight3, Weight4, Gertemp1, P_GER, Slwdtemp1,
P_SLWD, Gwptemp1, P_GWP, Acidtemp1, P_ACID, P_EFU, temp1, temp2, temp3, temp4,
temp5, temp6 : Real ;
RM1flowPct, RM2flowPct, RM3flowPct, RM4flowPct, RM5flowPct,
RP1flowPct, RP2flowPct, RP3flowPct, RP4flowPct : array[1..4] of real;

```



```

MP1flowPct,MP2flowPct,MP3flowPct,MP4flowPct: array[1..5] of real;

{ Extraction Variables }
IPEXtr,OPEXtr : Real;
TOPEXtrInd,GasEXtrInd,ElecEXtrInd,CO2EXtrInd,SO2EXtrInd,NOXEXtrInd,
COEXtrInd,SSEXtrInd,HEEXtrInd,NHEEXtrInd,HWEXtrInd,NHWEXtrInd,
PKGEXtrInd, GEREXtrInd,SLWDEXtrInd,GWPEXtrInd,ACIDEXtrInd,
EFUEXtrInd,IPEXtrInd,OPEXtrInd,ExtrPctInd,MrfEXtrInd :array[1..4]of real;
EIndN,EProN: Integer;

{ Processing Variables }
IPPSg,OPPSg : Real;
TOPPSgInd,GasPSgInd,ElecPSgInd,CO2PSgInd,SO2PSgInd,NOXPSgInd,COPsgInd,
SSPsgInd,HEPSgInd,NHEPSgInd,HWPsgInd,NHWPsgInd,PKGPSgInd,
TCOPsgInd,DMPsgInd,GERPSgInd,SLWDPsgInd,GWPPsgInd,ACIDPSgInd,
EFUPsgInd,PsgPctInd,BlendRatio,OPPSgInd,CPFPsg,TMRPPsg,IPPSgInd
:array[1..4]of real;
PsgPctInd1Pro,PsgPctInd2Pro,PsgPctInd3Pro,PsgPctInd4Pro,MrfPsgInd1Pro,
MrfPsgInd2Pro,MrfPsgInd3Pro,MrfPsgInd4Pro,RmfPsgInd1Pro,RpfPsgInd1Pro,
RmfPsgInd2Pro,RpfPsgInd2Pro,RmfPsgInd3Pro,RpfPsgInd3Pro,RmfPsgInd4Pro,
RpfPsgInd4Pro,OPPSgInd1Pro,OPPSgInd2Pro,OPPSgInd3Pro,OPPSgInd4Pro,
MRQPsgInd1Pro,
MRQPsgInd2Pro,MRQPsgInd3Pro,MRQPsgInd4Pro,RPMPsgInd1Pro,RPMPsgInd2Pro,
RPMPsgInd3Pro,RPMPsgInd4Pro,DMPsgInd1Pro,DMPsgInd2Pro,DMPsgInd3Pro,
DMPsgInd4Pro,IPPSgInd1Pro,IPPSgInd2Pro,IPPSgInd3Pro,IPPSgInd4Pro :
array[1..3] of real;
PIndN,PProN[,PProN1,PProN2,PProN3,PProN4,PProN5) : Integer;
{ Manufacturing Variables }
OPMfg,IPMfg : Real;
TOPMfgInd,GasMfgInd,ElecMfgInd,CO2MfgInd,SO2MfgInd,NOXMfgInd,COMfgInd,
SSMfgInd,HEMfgInd,NHEMfgInd,HWMfgInd,NHWMfgInd,PKGMfgInd,
TCOMfgInd,GERMfgInd,SLWDMfgInd,GWPMfgInd,ACIDMfgInd,
EFUMfgInd,MfgPctInd,OPMfgInd,CPFMfg,TMrmMfg,IPMfgInd,MRPMfgInd
:array[1..5]of real;
MfgPctInd1Pro,MfgPctInd2Pro,MfgPctInd3Pro,MfgPctInd4Pro,MfgPctInd5Pro,
OPMfgInd1Pro,OPMfgInd2Pro,OPMfgInd3Pro,OPMfgInd4Pro,OPMfgInd5Pro,
MRQMfgInd1Pro,MRQMfgInd2Pro,MRQMfgInd3Pro,MRQMfgInd4Pro,MRQMfgInd5Pro,
MrfMfgInd1Pro,MrfMfgInd2Pro,MrfMfgInd3Pro,MrfMfgInd4Pro,MrfMfgInd5Pro,
IPMfgInd1Pro,IPMfgInd2Pro,IPMfgInd3Pro,IPMfgInd4Pro,IPMfgInd5Pro,
MRPMfgInd1Pro,MRPMfgInd2Pro,MRPMfgInd3Pro,MRPMfgInd4Pro,MRPMfgInd5Pro,
RpfMfgInd1Pro,RpfMfgInd2Pro,RpfMfgInd3Pro,RpfMfgInd4Pro,
RpfMfgInd5Pro: array[1..4] of real;
{ MIndN : Real ; }
MIndN,MProN[,MProN1,MProN2,MProN3,MProN4,MProN5,MProN6,MProN7) : Integer ;
{ Recycling Variables }

IPRcy : Real ;
TOPRcyInd,GasRcyInd,ElecRcyInd,CO2RcyInd,SO2RcyInd,NOXRcyInd,CORcyInd,
SSRcyInd,HERcyInd,NHERcyInd,HWRcyInd,NHWRcyInd,PKGRcyInd,GERRcyInd,
SLWDRcyInd,GWPRcyInd,ACIDRcyInd,EFURcyInd,IPRcyInd,RcyPctInd,MRMRcyInd,
MRPRcyInd,OPRcyInd :array[1..4]of real;
RcyPctInd1Pro,RcyPctInd2Pro,RcyPctInd3Pro,RcyPctInd4Pro,
MRMRcyInd1Pro,MRMRcyInd2Pro,MRMRcyInd3Pro,MRMRcyInd4Pro,
MRPRcyInd1Pro,MRPRcyInd2Pro,MRPRcyInd3Pro,MRPRcyInd4Pro,
IPRcyInd1Pro,IPRcyInd2Pro,IPRcyInd3Pro,IPRcyInd4Pro,
OPRcyInd1Pro,OPRcyInd2Pro,OPRcyInd3Pro,OPRcyInd4Pro,
RmfRcyInd1Pro,RmfRcyInd2Pro,RmfRcyInd3Pro,RmfRcyInd4Pro,
RpfRcyInd1Pro,RpfRcyInd2Pro,RpfRcyInd3Pro,RpfRcyInd4Pro,

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    MlfRcyInd1Pro,MlfRcyInd2Pro,MlfRcyInd3Pro,MlfRcyInd4Pro: array[1..4] of
real; { Process variables }
    { RIndN : Real ;}
    RIndN,RProN(,RProN1,RProN2,RProN3,RProN4,RProN5 ): Integer ;

    { Disposal Variables }
    IPDisp : real ;
    DispPctInd : array[1..3] of real ;
    DIndN : Integer ;

    { SecUtz Variables }
    MrfUtz1,MlfUtz1,SwUtz1,LwUtz1,AeUtz1,EUtz1,MruUtz1,
    MlUtz1,SwgUtz1,LwgUtz1,AegUtz1,OPUtz1,TEUtz1,IPUtz1,OPUtz : real;

    { PriUtz Variables }
    MrfUtz2,RufUtz2, MlfUtz2,SwUtz2,LwUtz2,AeUtz2,
    EUtz2,Pw,Tmw,MruUtz2,MlUtz2,SwgUtz2,LwgUtz2,AegUtz2,OPUtz2,TEUtz2 : real ;
    matnum : integer ;

    procedure ImpactCalculation(K:Integer);
    procedure InventoryCalculation(Loop:Integer);

procedure TMain1.ClosedLoop1Click(Sender: TObject);
begin
    Loop := 1;K := 0;
    InventoryCalculation(Loop);
    ImpactCalculation(K);

    { INVENTORY ASSESSMENT CALCULATIONS }

    { Calculations for PRIMARY UTILIZATION }
    {Tmw := FcstDem * Pw ; { Total Mterial Weight }
    {MruUtz2 := RufUtz2 * Tmw/100 ; { Total Material Reutilized for the
forecasted demand}
    {MlUtz2 := MlfUtz2 * Tmw/100; { Total Material Lost for the forecasted
demand}
    {SwgUtz2 := SwUtz2 * FcstDem ; { Total Soilid Waste generated for the demand }
    {LwgUtz2 := LwUtz2 * FcstDem ; { '' Liquid '' }
    {AegUtz2 := AeUtz2 * FcstDem ; { Air '' }
    {TEUtz2 := EUtz2 * FcstDem ; { Total Energy consumed }
    {OPUtz2 := Tmw * MrfUtz2/100 ; { O/P material }

    { Calculations for SECONDARY UTILIZATION }
    {MrfUtz1 := 100 -(MlfUtz1);
    IPUtz1 := MruUtz2 ;
    OPUtz1 := IPUtz1 * MrfUtz1 /100;
    MlUtz1 := IPUtz1 * MlfUtz1/100;
    OPUtz := OPUtz1 + OPUtz2 ;
    SwgUtz1 := SwUtz1 * FcstDem * RufUtz2/100 ; { Total Solid Waste & Energy
consumed }
    {LwgUtz1 := LwUtz1 * FcstDem * RufUtz2/100 ; { at these stages are caculated
by }
    {AegUtz1 := AeUtz1 * FcstDem * RufUtz2/100 ; { by using the Reutilized
Demand of }
    {TEUtz1 := EUtz1 * FcstDem * RufUtz2/100 ; { of Utz2 }

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{ Calculations for RECYCLING STAGE }
{IPRcy := OPUtz ;
for I := 1 to RIndN do
begin
IPRcyInd[I] := IpRcy * RcyPctInd[I]/100 ;
end;
for J := 1 to RProN do
begin
IPRcyInd1Pro[J] := IPRcyInd[1] * RcyPctInd1Pro[J]/100;
MRMRcyInd1Pro[J] := IPRcyInd1Pro[J] * RmfRcyInd1Pro[J]/100;
MRPRcyInd1Pro[J] := IPRcyInd1Pro[J] * RpfRcyInd1Pro[J]/100 ;
Label1.Caption := FloatToStr(IPRcyInd1Pro[J]);
Label2.Caption := FloatToStr(MRMRcyInd1Pro[J]);
Label3.Caption := FloatToStr(MRPRcyInd1Pro[J]);

IPRcyInd2Pro[J] := IPRcyInd[2] * RcyPctInd2Pro[J]/100;
MRMRcyInd2Pro[J] := IPRcyInd2Pro[J] * RmfRcyInd2Pro[J]/100;
MRPRcyInd2Pro[J] := IPRcyInd2Pro[J] * RpfRcyInd2Pro[J]/100 ;

IPRcyInd3Pro[J] := IPRcyInd[3] * RcyPctInd3Pro[J]/100;
MRMRcyInd3Pro[J] := IPRcyInd3Pro[J] * RmfRcyInd3Pro[J]/100;
MRPRcyInd3Pro[J] := IPRcyInd3Pro[J] * RpfRcyInd3Pro[J]/100 ;

IPRcyInd4Pro[J] := IPRcyInd[4] * RcyPctInd4Pro[J]/100;
MRMRcyInd4Pro[J] := IPRcyInd4Pro[J] * RmfRcyInd4Pro[J]/100;
MRPRcyInd4Pro[J] := IPRcyInd4Pro[J] * RpfRcyInd4Pro[J]/100 ;
end;
for I :=1 to RIndN do
begin
for J :=1 to RProN do
begin
if I = 1 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd1Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd1Pro[J];
Label4.Caption := FloatToStr(MRMRcyInd[I]);
Label5.Caption := FloatToStr(MRPRcyInd[I]);
end;
if I = 2 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd2Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd2Pro[J];
end;
if I = 3 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd3Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd3Pro[J];
end;
if I = 4 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd4Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd4Pro[J];
end;
end;
end;

temp1 := MRMRcyInd[1]+ MRMRcyInd[2] + MRMRcyInd[3] + MRMRcyInd[4];
temp2 := MRPRcyInd[1]+ MRPRcyInd[2] + MRPRcyInd[3] + MRPRcyInd[4];

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{ Calculations for MANUFACTURING STAGE }
(OPMfg := Tmw ;

for I := 1 to MIndN do
begin
CPFMfg[I] := TCOMfgInd[I]/TOPMfgInd[I];
OPMfgInd[I] := OPMfg * MfgPctInd[I]/100 ;
COMfgInd[I] := CPMfg[I] * OPMfgInd[I];
end;
for J:= 1 to MProN do
begin
if MIndN = 1 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;
end;
if MIndN = 2 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;
end;
if MIndN = 3 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;

OPMfgInd3Pro[J] := OPMfgInd[3] * MfgPctInd3Pro[J]/100;
MRQMfgInd3Pro[J]:= OPMfgInd3Pro[J] / ( MrfMfgInd3Pro[J]/100) ;
end;
if MIndN = 4 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;

OPMfgInd3Pro[J] := OPMfgInd[3] * MfgPctInd3Pro[J]/100;
MRQMfgInd3Pro[J]:= OPMfgInd3Pro[J] / ( MrfMfgInd3Pro[J]/100) ;

OPMfgInd4Pro[J] := OPMfgInd[4] * MfgPctInd4Pro[J]/100;
MRQMfgInd4Pro[J]:= OPMfgInd4Pro[J] / ( MrfMfgInd4Pro[J]/100) ;
end;
if MIndN = 5 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;

OPMfgInd3Pro[J] := OPMfgInd[3] * MfgPctInd3Pro[J]/100;

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MRQMfgInd3Pro[J] := OPMfgInd3Pro[J] / ( MrfMfgInd3Pro[J]/100) ;

OPMfgInd4Pro[J] := OPMfgInd[4] * MfgPctInd4Pro[J]/100;
MRQMfgInd4Pro[J] := OPMfgInd4Pro[J] / ( MrfMfgInd4Pro[J]/100) ;

OPMfgInd5Pro[J] := OPMfgInd[5] * MfgPctInd5Pro[J]/100;
MRQMfgInd5Pro[J] := OPMfgInd5Pro[J] / ( MrfMfgInd5Pro[J]/100) ;
end;
end;
for I := 1 to MIndN do
begin
for K :=1 to RIndN do
begin
if ( I = 1) then
TMrmMfg[I] := TMrmMfg[I] + (MRMRcyInd[K] * RM1flowPct[K]/100);
if ( I = 2) then
TMrmMfg[I] := TMrmMfg[I] + (MRMRcyInd[K] * RM2flowPct[K]/100);
if ( I = 3) then
TMrmMfg[I] := TMrmMfg[I] + (MRMRcyInd[K] * RM3flowPct[K]/100);
if ( I = 4) then
TMrmMfg[I] := TMrmMfg[I] + (MRMRcyInd[K] * RM4flowPct[K]/100);
if ( I = 5) then
TMrmMfg[I] := TMrmMfg[I] + (MRMRcyInd[K] * RM5flowPct[K]/100);
end;
end;

for J :=1 to MProN do
begin
IPMfgInd1Pro[J] := MRQMfgInd1Pro[J] - ( MfgPctInd1Pro[J] * TMrmMfg[1]/100);
MRPMfgInd1Pro[J] := MRQMfgInd1Pro[J] * ( RpfMfgInd1Pro[J]/100);

IPMfgInd2Pro[J] := MRQMfgInd2Pro[J] - ( MfgPctInd2Pro[J] * TMrmMfg[1]/100);
MRPMfgInd2Pro[J] := MRQMfgInd2Pro[J] * ( RpfMfgInd2Pro[J]/100);

IPMfgInd3Pro[J] := MRQMfgInd3Pro[J] - ( MfgPctInd3Pro[J] * TMrmMfg[1]/100);
MRPMfgInd3Pro[J] := MRQMfgInd3Pro[J] * ( RpfMfgInd3Pro[J]/100) ;

IPMfgInd4Pro[J] := MRQMfgInd4Pro[J] - ( MfgPctInd4Pro[J] * TMrmMfg[1]/100);
MRPMfgInd4Pro[J] := MRQMfgInd4Pro[J] * ( RpfMfgInd4Pro[J]/100) ;

IPMfgInd5Pro[J] := MRQMfgInd5Pro[J] - ( MfgPctInd5Pro[J] * TMrmMfg[1]/100);
MRPMfgInd5Pro[J] := MRQMfgInd5Pro[J] * ( RpfMfgInd5Pro[J]/100) ;
end;

for I :=1 to MIndN do
begin
for J :=1 to MProN do
begin
if I = 1 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd1Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd1Pro[J];
end;
if I = 2 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd2Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd2Pro[J];
end;

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if I = 3 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd3Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd3Pro[J];
end;
if I = 4 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd4Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd4Pro[J];
end;
if I = 5 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd5Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd5Pro[J];
end;
end;
end;

for I:=1 to MIndN do
begin
IPMfg := IPMfg + IPMfgInd[I] ;
temp3 := temp3 + MRPMfgInd[I];
end;

( Calculations for PROCESSING STAGE )
{OPPsg := IPMfg ;

for I := 1 to PIndN do
begin
CPFPsg[I] := TCOPsgInd[I]/TOPPsgInd[I];
OPPsgInd[I] := OPPsg * PsgPctInd[I]/100 ;
COPsgInd[I] := CPFPsg[I] * OPPsgInd[I];
end;
for J:= 1 to PProN do
begin
if PIndN = 1 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J]:= OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;
end;
if PIndN = 2 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J]:= OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;

OPPsgInd2Pro[J] := OPPsgInd[2] * PsgPctInd2Pro[J]/100;
MRQPsgInd2Pro[J]:= OPPsgInd2Pro[J] / ( MrfPsgInd2Pro[J]/100) ;
end;

if PIndN = 3 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J]:= OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;

OPPsgInd2Pro[J] := OPPsgInd[2] * PsgPctInd2Pro[J]/100;
MRQPsgInd2Pro[J]:= OPPsgInd2Pro[J] / ( MrfPsgInd2Pro[J]/100) ;

OPPsgInd3Pro[J] := OPPsgInd[3] * PsgPctInd3Pro[J]/100;

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MRQPsgInd3Pro[J]:= OPPsgInd3Pro[J] / ( MrfPsgInd3Pro[J]/100) ;
end;

if PIndN = 4 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J]:= OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;

OPPsgInd2Pro[J] := OPPsgInd[2] * PsgPctInd2Pro[J]/100;
MRQPsgInd2Pro[J]:= OPPsgInd2Pro[J] / ( MrfPsgInd2Pro[J]/100) ;

OPPsgInd3Pro[J] := OPPsgInd[3] * PsgPctInd3Pro[J]/100;
MRQPsgInd3Pro[J]:= OPPsgInd3Pro[J] / ( MrfPsgInd3Pro[J]/100) ;

OPPsgInd4Pro[J] := OPPsgInd[4] * PsgPctInd4Pro[J]/100;
MRQPsgInd4Pro[J]:= OPPsgInd4Pro[J] / ( MrfPsgInd4Pro[J]/100) ;
end;
end;

for I := 1 to PIndN do
begin
for K :=1 to RIndN do
begin
if ( I = 1) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP1flowPct[K]/100);
if ( I = 2) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP2flowPct[K]/100);
if ( I = 3) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP3flowPct[K]/100);
if ( I = 4) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP4flowPct[K]/100);
end;
for K :=1 to MIndN do
begin
if ( I = 1) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP1flowPct[K]/100);
if ( I = 2) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP2flowPct[K]/100);
if ( I = 3) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP3flowPct[K]/100);
if ( I = 4) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP4flowPct[K]/100);
end;
end;

for J:= 1 to PProN do
begin
if ( BlendRatio[1]* MRQPsgInd1Pro[J]/100) > (TMRPPsg[1] *
PsgPctInd1Pro[J]/100)
then RPMPsgInd1Pro[J] := TMrpPsg[1] * PsgPctInd1Pro[J]/100
else RPMPsgInd1Pro[J] := BlendRatio[1] * MRQPsgInd1Pro[J]/100;
DMPsgInd1Pro[J] := (TMRPPsg[1] * PsgPctInd1Pro[J]/100 -
( BlendRatio[1]*MRQPsgInd1Pro[J]/100));
if DMPsgInd1Pro[J] < 0 then DMPsgInd1Pro[J] := 0;
IPPsgInd1Pro[J] := MRQPsgInd1Pro[J] - RPMPsgInd1Pro[J];

if ( BlendRatio[2]* MRQPsgInd2Pro[J]/100) > (TMRPPsg[2] *
PsgPctInd2Pro[J]/100)

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then RPMPsgInd2Pro[J] := TMrpPsg[2] * PsgPctInd2Pro[J]/100
else RPMPsgInd2Pro[J] := BlendRatio[2] * MRQPsgInd2Pro[J]/100;
DMPsgInd2Pro[J] := (TMRPPsg[2] * PsgPctInd2Pro[J]/100 -
( BlendRatio[2]*MRQPsgInd2Pro[J]/100));
if DMPsgInd2Pro[J] < 0 then DMPsgInd2Pro[J] := 0;
IPPsInd2Pro[J] := MRQPsgInd2Pro[J] - RPMPsgInd2Pro[J];

if ( BlendRatio[3]* MRQPsgInd3Pro[J]/100) > (TMRPPsg[3] *
PsgPctInd3Pro[J]/100)
then RPMPsgInd3Pro[J] := TMrpPsg[3] * PsgPctInd3Pro[J]/100
else RPMPsgInd3Pro[J] := BlendRatio[3] * MRQPsgInd3Pro[J]/100;
DMPsgInd3Pro[J] := (TMRPPsg[3] * PsgPctInd3Pro[J]/100 -
( BlendRatio[3]*MRQPsgInd3Pro[J]/100));
if DMPsgInd3Pro[J] < 0 then DMPsgInd3Pro[J] := 0;
IPPsInd3Pro[J] := MRQPsgInd3Pro[J] - RPMPsgInd3Pro[J];

if ( BlendRatio[4]* MRQPsgInd4Pro[J]/100) > (TMRPPsg[4] *
PsgPctInd4Pro[J]/100)
then RPMPsgInd4Pro[J] := TMrpPsg[4] * PsgPctInd4Pro[J]/100
else RPMPsgInd4Pro[J] := BlendRatio[4] * MRQPsgInd4Pro[J]/100;
DMPsgInd4Pro[J] := (TMRPPsg[4] * PsgPctInd4Pro[J]/100 -
( BlendRatio[4]*MRQPsgInd4Pro[J]/100));
if DMPsgInd4Pro[J] < 0 then DMPsgInd4Pro[J] := 0;
IPPsInd4Pro[J] := MRQPsgInd4Pro[J] - RPMPsgInd4Pro[J];
end;

for I :=1 to PIndN do
begin
for J :=1 to PProN do
begin
if I = 1 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd1Pro[J];
IPPsInd[I] := IPPsgInd[I] + IPPsgInd1Pro[J];
end;
if I = 2 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd2Pro[J];
IPPsInd[I] := IPPsgInd[I] + IPPsgInd2Pro[J];
end;
if I = 3 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd3Pro[J];
IPPsInd[I] := IPPsgInd[I] + IPPsgInd3Pro[J];
end;
if I = 4 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd4Pro[J];
IPPsInd[I] := IPPsgInd[I] + IPPsgInd4Pro[J];
end;
end;
end;

for I:=1 to PIndN do
begin
IPPs := IPPsg + IPPsgInd[I] ;
temp4 := temp4 + DMPsgInd[I];
temp5 := temp5 + TMRPPsg[I];

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end;

{ Calculations for EXTRACTION STAGE }

{ OPExtr := IPPsg ;
for I := 1 to EIndN do
begin
OPExtrInd[I] := OPExtr * ExtrPctInd[I]/ 100;
IPExtrInd[I] := OPExtrInd[I] / ( MrfExtrInd[I]/100);
IPExtr := IPExtr + IPExtrInd[I] ;
end;

{ PRODUCT CALCULATIONS }

{for I:=1 to EIndN do
begin
Gertempl := Gertempl + (OPExtrInd[I] * GERExtrInd[I] / TOPExtrInd[I]);
Slwdtempl := Slwdtempl + (OPExtrInd[I]*SLWDExtrInd[I]/TOPExtrInd[I]);
Gwptempl := Gwptempl + (OPExtrInd[I] * GWPExtrInd[I]/TOPExtrInd[I]) ;
Acidtempl := Acidtempl + (OPExtrInd[I]* ACIDExtrInd[I]/TOPExtrInd[I]);
end;
for I:=1 to RIndN do
begin
{Gertempl := Gertempl + (OPRcyInd[I] * GERRcyInd[I] / TOPRcyInd[I]);
Slwdtempl := Slwdtempl + (OPRcyInd[I]*SLWDRcyInd[I]/TOPRcyInd[I]);
Gwptempl := Gwptempl + (OPRcyInd[I] * GWPRcyInd[I]/TOPRcyInd[I]) ;
Acidtempl := Acidtempl + (OPRcyInd[I]* ACIDRcyInd[I]/TOPRcyInd[I]);
{end;
for I:=1 to PIndN do
begin
Gertempl := Gertempl + (OPPsgInd[I] * GERPsgInd[I]
/(TOPPsgInd[I]+TCOPsgInd[I]));
Slwdtempl := Slwdtempl +
(OPPsgInd[I]*SLWDPsgInd[I]/(TOPPsgInd[I]+TCOPsgInd[I]));
Gwptempl := Gwptempl + (OPPsgInd[I] *
GWPPsgInd[I]/(TOPPsgInd[I]+TCOPsgInd[I]));
Acidtempl := Acidtempl + (OPPsgInd[I]*
ACIDPsgInd[I]/(TOPPsgInd[I]+TCOPsgInd[I]));
end;
for I:=1 to MIndN do
begin
Gertempl := Gertempl + (OPMfgInd[I] * GERMfgInd[I]
/(TOPMfgInd[I]+TCOMfgInd[I]));
Slwdtempl := Slwdtempl +
(OPMfgInd[I]*SLWDMfgInd[I]/(TOPMfgInd[I]+TCOMfgInd[I]));
Gwptempl := Gwptempl + (OPMfgInd[I] *
GWPMfgInd[I]/(TOPMfgInd[I]+TCOMfgInd[I]));
Acidtempl := Acidtempl + (OPMfgInd[I]*
ACIDMfgInd[I]/(TOPMfgInd[I]+TCOMfgInd[I]));
end;

P_GER := Gertempl + TEUtz1 + TEUtz2;
P_SLWD := Slwdtempl + SwgUtz2 + LwgUtz2 + SwgUtz1+ LwgUtz1 ;
P_GWP := Gwptempl ;
P_ACID := Acidtempl ;
P_EFU:= weight1 * P_GER + weight2 * P_SLWD + weight3 * P_GWP + weight4 *
P_ACID;}
end;

```

```

procedure ImpactCalculation(K:Integer);
begin
  { IMPACT ASSESSMENT CALCULATIONS }

  { INDUSTRY Calculations }
  { Extraction }
  for counter :=1 to EIndN do { !!OK HERE !!}
  begin
    GERExtrInd[counter] := ( 163656000 * GASExtrInd[counter] +
    11700 * ELECExtrInd[counter] ) ;

    SLWDExtrInd[counter] := ( SSExtrInd[counter] + HEEextrInd[counter] +
    NHEExtrInd[counter] + NHWExtrInd[counter] + PKGExtrInd[counter] +
    0.20 * ELECExtrInd[counter] ) ;

    GWPExtrInd[counter] := ( 1 * ( CO2ExtrInd[counter] +
    0.640*ELECExtrInd[counter]
    + 10455.80 * GASExtrInd[counter] ) + 2 * ( COExtrInd[counter] +
    86.37*GASExtrInd[counter] ) + 40*( NOXExtrInd[counter] +
    21.82*GASExtrInd[counter] ) );

    ACIDExtrInd[counter] := ( SO2ExtrInd[counter] + NOXExtrInd[counter] );

    EFUExtrInd[counter] := ( Weight1*GERExtrInd[counter] +
    Weight2*SLWDExtrInd[counter] + Weight3*GWPExtrInd[counter] +
    Weight4*ACIDExtrInd[counter] ) ;
  end;

  { Processing }
  for counter := 1 to PIndN do { !!OK HERE !! }
  begin
    GERPsgInd[counter] := ( 163656000 * GASPsgInd[counter] +
    11700 * ELECPsgInd[counter] ) ;

    SLWDPsgInd[counter] := ( SSPsgInd[counter] + HEPsgInd[counter] +
    NHEPsgInd[counter] + NHWPsgInd[counter] + PKGPsgInd[counter] +
    0.20 * ELECPsgInd[counter] +DMPsgInd[counter] ) ;

    GWPPsgInd[counter] := ( 1 * ( CO2PsgInd[counter] + 0.640*ELECPsgInd[counter]
    + 10455.80 * GASPsgInd[counter] ) + 2 * ( COPsgInd[counter] +
    86.37*GASPsgInd[counter] ) + 40*( NOXPsgInd[counter] +
    21.82*GASPsgInd[counter] ) );

    ACIDPsgInd[counter] := ( SO2PsgInd[counter] + NOXPsgInd[counter] );

    EFUPsgInd[counter] := ( Weight1*GERPsgInd[counter] +
    Weight2*SLWDPsgInd[counter] + Weight3*GWPPsgInd[counter] +
    Weight4*ACIDPsgInd[counter] ) ;
  end;

  { Manufacturing }
  for counter := 1 to MIndN do { !!OK HERE !!}
  begin
    GERMfgInd[counter] := ( 163656000 * GASMfgInd[counter] +
    11700 * ELECMfgInd[counter] ) ;

    SLWDMfgInd[counter] := ( SSMfgInd[counter] + HEMfgInd[counter] +

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NHMFgInd[counter] + NHWMfgInd[counter] + PKGMfgInd[counter] +
0.20 * ELECMfgInd[counter] ) ;

GWPMfgInd[counter] := ( 1 * ( CO2MfgInd[counter] + 0.640*ELECMfgInd[counter]
+ 10455.80 * GASMfgInd[counter] ) + 2 * ( COMfgInd[counter] +
86.37*GASMfgInd[counter] ) + 40*( NOXMfgInd[counter] +
21.82*GASMfgInd[counter] ) );

ACIDMfgInd[counter] := ( SO2MfgInd[counter] + NOXMfgInd[counter] );

EFUMfgInd[counter] := ( Weight1*GERMfgInd[counter] +
Weight2*SLWDMfgInd[counter] + Weight3*GWPMfgInd[counter] +
Weight4*ACIDMfgInd[counter] ) ;
end;

( Recycling )
for counter := 1 to RIndN do      ( !!OK HERE !!)
begin
GERRcyInd[counter] := ( 163656000 * GASRcyInd[counter] +
11700 * ELECRcyInd[counter] ) ;

SLWDRcyInd[counter] := ( SSRcyInd[counter] + HERcyInd[counter] +
NHERcyInd[counter] + NHWRcyInd[counter] + PKGRcyInd[counter] +
0.20 * ELECRcyInd[counter] ) ;

GWPRcyInd[counter] := ( 1 * ( CO2RcyInd[counter] + 0.640*ELECRcyInd[counter]
+ 10455.80 * GASRcyInd[counter] ) + 2 * ( CORcyInd[counter] +
86.37*GASRcyInd[counter] ) + 40*( NOXRcyInd[counter] +
21.82*GASRcyInd[counter] ) );

ACIDRcyInd[counter] := ( SO2RcyInd[counter] + NOXRcyInd[counter] );

EFURcyInd[counter] := ( Weight1*GERRcyInd[counter] +
Weight2*SLWDRcyInd[counter] + Weight3*GWPRcyInd[counter] +
Weight4*ACIDRcyInd[counter] ) ;
end;

( PRODUCT CALCULATIONS )
for I:=1 to EIndN do
begin
Gertempl := Gertempl + (OPExtrInd[I] * GERExtrInd[I] / TOPExtrInd[I]);
Slwdtempl := Slwdtempl + (OPExtrInd[I]*SLWDExtrInd[I]/TOPExtrInd[I]);
Gwptempl := Gwptempl + (OPExtrInd[I] * GWPExtrInd[I]/TOPExtrInd[I]);
Acidtempl := Acidtempl + (OPExtrInd[I]* ACIDExtrInd[I]/TOPExtrInd[I]);
end;
for I:=1 to RIndN do
begin
Gertempl := Gertempl + (OPRcyInd[I] * GERRcyInd[I] / TOPRcyInd[I]);
Slwdtempl := Slwdtempl + (OPRcyInd[I]*SLWDRcyInd[I]/TOPRcyInd[I]);
Gwptempl := Gwptempl + (OPRcyInd[I] * GWPRcyInd[I]/TOPRcyInd[I]);
Acidtempl := Acidtempl + (OPRcyInd[I]* ACIDRcyInd[I]/TOPRcyInd[I]);
end;
for I:=1 to PIndN do
begin
Gertempl := Gertempl + (OPPsgInd[I] * GERPsgInd[I]
/(TOPPsgInd[I]+TCOPsgInd[I]));
Slwdtempl := Slwdtempl +
(OPPsgInd[I]*SLWDPsgInd[I]/(TOPPsgInd[I]+TCOPsgInd[I]));

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Gwptempl := Gwptempl + (OPPsgInd[I] *
GWPPsgInd[I]/(TOPPsgInd[I]+TCOPsgInd[I]));
Acidtempl := Acidtempl + (OPPsgInd[I]*
ACIDPsgInd[I]/(TOPPsgInd[I]+TCOPsgInd[I]));
end;
for I:=1 to MIndN do
begin
Gertempl := Gertempl + (OPMfgInd[I] * GERMfgInd[I]
/(TOPMfgInd[I]+TCOMfgInd[I]));
Slwdtempl := Slwdtempl +
(OPMfgInd[I]*SLWDMfgInd[I]/(TOPMfgInd[I]+TCOMfgInd[I]));
Gwptempl := Gwptempl + (OPMfgInd[I] *
GWPMfgInd[I]/(TOPMfgInd[I]+TCOMfgInd[I]));
Acidtempl := Acidtempl + (OPMfgInd[I]*
ACIDMfgInd[I]/(TOPMfgInd[I]+TCOMfgInd[I]));
end;

P_GER := Gertempl + TEUtz1 + TEUtz2;
P_GER := P_GER / 1000 ; { taking care of Difference in Units:Kgs & Tonnes }
P_SLWD := Slwdtempl + SwgUtz2 + LwgUtz2 + SwgUtz1+ LwgUtz1 ;
P_SLWD := P_SLWD / 1000 ;{ taking care of Difference in Units:Kgs & Tonnes }
P_GWP := Gwptempl ;
P_GWP := P_GWP / 1000 ; { taking care of Difference in Units:Kgs & Tonnes }
P_ACID := Acidtempl ;
P_ACID := P_ACID / 1000 ; { taking care of Difference in Units:Kgs & Tonnes }
P_EFU:= Weight1 * P_GER + Weight2 * P_SLWD + Weight3 * P_GWP + Weight4 *
P_ACID;
IPDisp := P_SLWD * 1000 + temp4;
end;

procedure InventoryCalculation(Loop:Integer);
begin
{ INVENTORY ASSESSMENT CALCULATIONS }

{ Calculations for PRIMARY UTILIZATION }
Tmw := FcstDem * Pw ; { Total Mterial Weight }
MruUtz2 := RufUtz2 * Tmw/100 ; { Total Material Reutilized for the
forecasted demand}
MlUtz2 := MlfUtz2 * Tmw/100; { Total Material Lost for the forecasted
demand}
SwgUtz2 := SwUtz2 * FcstDem ; { Total Soild Waste generated for the demand }
LwgUtz2 := LwUtz2 * FcstDem ; { ' ' Liquid ' ' }
AegUtz2 := AeUtz2 * FcstDem ; { ' ' Air ' ' }
TEUtz2 := EUtz2 * FcstDem ; { Total Energy consumed }
OPUtz2 := Tmw * MrfUtz2/100 ; { O/P material }

{ Calculations for SECONDARY UTILIZATION }
MrfUtz1 := 100 -(MlfUtz1);
IPUtz1 := MruUtz2 ;
OPUtz1 := IPUtz1 * MrfUtz1 /100;
MlUtz1 := IPUtz1 * MlfUtz1/100;
OPUtz := OPUtz1 + OPUtz2 ;
SwgUtz1 := SwUtz1 * FcstDem * RufUtz2/100 ; { Total Solid Waste & Energy
consumed }
LwgUtz1 := LwUtz1 * FcstDem * RufUtz2/100 ; { at these stages are caculated
by }
AegUtz1 := AeUtz1 * FcstDem * RufUtz2/100 ; { by using the Reutilized Demand
of }

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TEUtz1 := EUTz1 * FcstDem * RufUtz2/100 ;    { of Utz2 }

{ Calculations for RECYCLING STAGE }
IPRcy := OPUtz ;
for I := 1 to RIndN do
begin
IPRcyInd[I] := IPRcy * RcyPctInd[I]/100 ;
end;
for J := 1 to RProN do
begin
IPRcyInd1Pro[J] := IPRcyInd[1] * RcyPctInd1Pro[J]/100;
MRMRcyInd1Pro[J] := IPRcyInd1Pro[J] * RmfRcyInd1Pro[J]/100;
MRPRcyInd1Pro[J] := IPRcyInd1Pro[J] * RpfRcyInd1Pro[J]/100 ;
OPRcyInd1Pro[J] := IPRcyInd1Pro[J] * MlfRcyInd1Pro[J]/100;
{Label1.Caption := FloatToStr(IPRcyInd1Pro[J]);
Label2.Caption := FloatToStr(MRMRcyInd1Pro[J]);
Label3.Caption := FloatToStr(MRPRcyInd1Pro[J]);}

IPRcyInd2Pro[J] := IPRcyInd[2] * RcyPctInd2Pro[J]/100;
MRMRcyInd2Pro[J] := IPRcyInd2Pro[J] * RmfRcyInd2Pro[J]/100;
MRPRcyInd2Pro[J] := IPRcyInd2Pro[J] * RpfRcyInd2Pro[J]/100 ;
OPRcyInd2Pro[J] := IPRcyInd2Pro[J] * MlfRcyInd2Pro[J]/100;

IPRcyInd3Pro[J] := IPRcyInd[3] * RcyPctInd3Pro[J]/100;
MRMRcyInd3Pro[J] := IPRcyInd3Pro[J] * RmfRcyInd3Pro[J]/100;
MRPRcyInd3Pro[J] := IPRcyInd3Pro[J] * RpfRcyInd3Pro[J]/100 ;
OPRcyInd3Pro[J] := IPRcyInd3Pro[J] * MlfRcyInd3Pro[J]/100;

IPRcyInd4Pro[J] := IPRcyInd[4] * RcyPctInd4Pro[J]/100;
MRMRcyInd4Pro[J] := IPRcyInd4Pro[J] * RmfRcyInd4Pro[J]/100;
MRPRcyInd4Pro[J] := IPRcyInd4Pro[J] * RpfRcyInd4Pro[J]/100 ;
OPRcyInd4Pro[J] := IPRcyInd4Pro[J] * MlfRcyInd4Pro[J]/100;
end;

for I :=1 to RIndN do
begin
for J :=1 to RProN do
begin
if I = 1 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd1Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd1Pro[J];
OPRcyInd[I] := OPRcyInd[I] + OPRcyInd1Pro[J];
{Label4.Caption := FloatToStr(MRMRcyInd[I]);
Label5.Caption := FloatToStr(MRPRcyInd[I]);}
end;
if I = 2 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd2Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd2Pro[J];
OPRcyInd[I] := OPRcyInd[I] + OPRcyInd2Pro[J];
end;
if I = 3 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd3Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd3Pro[J];
OPRcyInd[I] := OPRcyInd[I] + OPRcyInd3Pro[J];
end;

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if I = 4 then
begin
MRMRcyInd[I] := MRMRcyInd[I] + MRMRcyInd4Pro[J];
MRPRcyInd[I] := MRPRcyInd[I] + MRPRcyInd4Pro[J];
OPRcyInd[I] := OPRcyInd[I] + OPRcyInd4Pro[J];
end;
end;
end;

temp1 := MRMRcyInd[1]+ MRMRcyInd[2] + MRMRcyInd[3] + MRMRcyInd[4];
temp2 := MRPRcyInd[1]+ MRPRcyInd[2] + MRPRcyInd[3] + MRPRcyInd[4];
temp6 := OPRcyInd[1] + OPRcyInd[2] + OPRcyInd[3] + OPRcyInd[4] ;

( Calculations for MANUFACTURING STAGE )
OPMfg := Tmw ;
for I := 1 to MIndN do
begin
CPFMfg[I] := TCOMfgInd[I]/TOPMfgInd[I];
OPMfgInd[I] := OPMfg * MfgPctInd[I]/100 ;
COMfgInd[I] := CPMfg[I] * OPMfgInd[I];
end;
for J:= 1 to MProN do
begin
if MIndN = 1 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;
end;
if MIndN = 2 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;
end;
if MIndN = 3 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;

OPMfgInd3Pro[J] := OPMfgInd[3] * MfgPctInd3Pro[J]/100;
MRQMfgInd3Pro[J]:= OPMfgInd3Pro[J] / ( MrfMfgInd3Pro[J]/100) ;
end;
if MIndN = 4 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J]:= OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J]:= OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;

OPMfgInd3Pro[J] := OPMfgInd[3] * MfgPctInd3Pro[J]/100;
MRQMfgInd3Pro[J]:= OPMfgInd3Pro[J] / ( MrfMfgInd3Pro[J]/100) ;

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OPMfgInd4Pro[J] := OPMfgInd[4] * MfgPctInd4Pro[J]/100;
MRQMfgInd4Pro[J] := OPMfgInd4Pro[J] / ( MrfMfgInd4Pro[J]/100) ;
end;
if MIndN = 5 then
begin
OPMfgInd1Pro[J] := OPMfgInd[1] * MfgPctInd1Pro[J]/100;
MRQMfgInd1Pro[J] := OPMfgInd1Pro[J] / ( MrfMfgInd1Pro[J]/100) ;

OPMfgInd2Pro[J] := OPMfgInd[2] * MfgPctInd2Pro[J]/100;
MRQMfgInd2Pro[J] := OPMfgInd2Pro[J] / ( MrfMfgInd2Pro[J]/100) ;

OPMfgInd3Pro[J] := OPMfgInd[3] * MfgPctInd3Pro[J]/100;
MRQMfgInd3Pro[J] := OPMfgInd3Pro[J] / ( MrfMfgInd3Pro[J]/100) ;

OPMfgInd4Pro[J] := OPMfgInd[4] * MfgPctInd4Pro[J]/100;
MRQMfgInd4Pro[J] := OPMfgInd4Pro[J] / ( MrfMfgInd4Pro[J]/100) ;

OPMfgInd5Pro[J] := OPMfgInd[5] * MfgPctInd5Pro[J]/100;
MRQMfgInd5Pro[J] := OPMfgInd5Pro[J] / ( MrfMfgInd5Pro[J]/100) ;
end;
end;
if Loop = 1 then    { Consideration for Closed Loop Recycling Only}
begin
for I := 1 to MIndN do
begin
for K :=1 to RIndN do
begin
if ( I = 1) then
TMrMfg[I] := TMrMfg[I] + (MRMRcyInd[K] * RM1flowPct[K]/100);
if ( I = 2) then
TMrMfg[I] := TMrMfg[I] + (MRMRcyInd[K] * RM2flowPct[K]/100);
if ( I = 3) then
TMrMfg[I] := TMrMfg[I] + (MRMRcyInd[K] * RM3flowPct[K]/100);
if ( I = 4) then
TMrMfg[I] := TMrMfg[I] + (MRMRcyInd[K] * RM4flowPct[K]/100);
if ( I = 5) then
TMrMfg[I] := TMrMfg[I] + (MRMRcyInd[K] * RM5flowPct[K]/100);
end;
end;
end;

for J :=1 to MProN do
begin
IPMfgInd1Pro[J] := MRQMfgInd1Pro[J] - ( MfgPctInd1Pro[J] * TMrMfg[1]/100);
MRPMfgInd1Pro[J] := MRQMfgInd1Pro[J] * ( RpfMfgInd1Pro[J]/100);

IPMfgInd2Pro[J] := MRQMfgInd2Pro[J] - ( MfgPctInd2Pro[J] * TMrMfg[1]/100);
MRPMfgInd2Pro[J] := MRQMfgInd2Pro[J] * ( RpfMfgInd2Pro[J]/100);

IPMfgInd3Pro[J] := MRQMfgInd3Pro[J] - ( MfgPctInd3Pro[J] * TMrMfg[1]/100);
MRPMfgInd3Pro[J] := MRQMfgInd3Pro[J] * ( RpfMfgInd3Pro[J]/100) ;

IPMfgInd4Pro[J] := MRQMfgInd4Pro[J] - ( MfgPctInd4Pro[J] * TMrMfg[1]/100);
MRPMfgInd4Pro[J] := MRQMfgInd4Pro[J] * ( RpfMfgInd4Pro[J]/100) ;

IPMfgInd5Pro[J] := MRQMfgInd5Pro[J] - ( MfgPctInd5Pro[J] * TMrMfg[1]/100);
MRPMfgInd5Pro[J] := MRQMfgInd5Pro[J] * ( RpfMfgInd5Pro[J]/100) ;
end;

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for I :=1 to MIndN do
begin
for J :=1 to MProN do
begin
if I = 1 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd1Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd1Pro[J];
end;
if I = 2 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd2Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd2Pro[J];
end;
if I = 3 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd3Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd3Pro[J];
end;
if I = 4 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd4Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd4Pro[J];
end;
if I = 5 then
begin
IPMfgInd[I] := IPMfgInd[I] + IPMfgInd5Pro[J];
MRPMfgInd[I] := MRPMfgInd[I] + MRPMfgInd5Pro[J];
end;
end;
end;

for I:=1 to MIndN do
begin
IPMfg := IPMfg + IPMfgInd[I] ;
temp3 := temp3 + MRPMfgInd[I];
end;

{ Calculations for Processing Stage }
OPPsg := IPMfg ;
for I := 1 to PIndN do
begin
CPFPsg[I] := TCOPsgInd[I]/TOPPsgInd[I];
OPPsgInd[I] := OPPsg * PsgPctInd[I]/100 ;
COPsgInd[I] := CPFPsg[I] * OPPsgInd[I];
end;
for J:= 1 to PProN do
begin
if PIndN = 1 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J]:= OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;
end;

if PIndN = 2 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;

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MRQPsgInd1Pro[J] := OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;

OPPsgInd2Pro[J] := OPPsgInd[2] * PsgPctInd2Pro[J]/100;
MRQPsgInd2Pro[J] := OPPsgInd2Pro[J] / ( MrfPsgInd2Pro[J]/100) ;
end;

if PIndN = 3 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J] := OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;

OPPsgInd2Pro[J] := OPPsgInd[2] * PsgPctInd2Pro[J]/100;
MRQPsgInd2Pro[J] := OPPsgInd2Pro[J] / ( MrfPsgInd2Pro[J]/100) ;

OPPsgInd3Pro[J] := OPPsgInd[3] * PsgPctInd3Pro[J]/100;
MRQPsgInd3Pro[J] := OPPsgInd3Pro[J] / ( MrfPsgInd3Pro[J]/100) ;
end;

if PIndN = 4 then
begin
OPPsgInd1Pro[J] := OPPsgInd[1] * PsgPctInd1Pro[J]/100;
MRQPsgInd1Pro[J] := OPPsgInd1Pro[J] / ( MrfPsgInd1Pro[J]/100) ;

OPPsgInd2Pro[J] := OPPsgInd[2] * PsgPctInd2Pro[J]/100;
MRQPsgInd2Pro[J] := OPPsgInd2Pro[J] / ( MrfPsgInd2Pro[J]/100) ;

OPPsgInd3Pro[J] := OPPsgInd[3] * PsgPctInd3Pro[J]/100;
MRQPsgInd3Pro[J] := OPPsgInd3Pro[J] / ( MrfPsgInd3Pro[J]/100) ;

OPPsgInd4Pro[J] := OPPsgInd[4] * PsgPctInd4Pro[J]/100;
MRQPsgInd4Pro[J] := OPPsgInd4Pro[J] / ( MrfPsgInd4Pro[J]/100) ;
end;
end;

if Loop = 1 then      { Consideration for Closed Loop Recycling Only}
begin
for I := 1 to PIndN do
begin
for K :=1 to RIndN do
begin
if ( I = 1) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP1flowPct[K]/100);
if ( I = 2) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP2flowPct[K]/100);
if ( I = 3) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP3flowPct[K]/100);
if ( I = 4) then
TMRPPsg[I] := TMRPPsg[I] + (MRPRcyInd[K] * RP4flowPct[K]/100);
end;
for K :=1 to MIndN do
begin
if ( I = 1) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP1flowPct[K]/100);
if ( I = 2) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP2flowPct[K]/100);
if ( I = 3) then
TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP3flowPct[K]/100);
if ( I = 4) then

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TMRPPsg[I] := TMRPPsg[I] + (MRPMfgInd[K] * MP4flowPct[K]/100);
end;
end;
end;

for J:= 1 to PProN do
begin
if ( BlendRatio[1]* MRQPsgInd1Pro[J]/100) > (TMRPPsg[1] *
PsgPctInd1Pro[J]/100)
then RPMPsgInd1Pro[J] := TMrpPsg[1] * PsgPctInd1Pro[J]/100
else RPMPsgInd1Pro[J] := BlendRatio[1] * MRQPsgInd1Pro[J]/100;
DMPsgInd1Pro[J] := (TMRPPsg[1] * PsgPctInd1Pro[J]/100 -
( BlendRatio[1]*MRQPsgInd1Pro[J]/100));
if DMPsgInd1Pro[J] < 0 then DMPsgInd1Pro[J] := 0;
IPPsgInd1Pro[J] := MRQPsgInd1Pro[J] - RPMPsgInd1Pro[J];

if ( BlendRatio[2]* MRQPsgInd2Pro[J]/100) > (TMRPPsg[2] *
PsgPctInd2Pro[J]/100)
then RPMPsgInd2Pro[J] := TMrpPsg[2] * PsgPctInd2Pro[J]/100
else RPMPsgInd2Pro[J] := BlendRatio[2] * MRQPsgInd2Pro[J]/100;
DMPsgInd2Pro[J] := (TMRPPsg[2] * PsgPctInd2Pro[J]/100 -
( BlendRatio[2]*MRQPsgInd2Pro[J]/100));
if DMPsgInd2Pro[J] < 0 then DMPsgInd2Pro[J] := 0;
IPPsgInd2Pro[J] := MRQPsgInd2Pro[J] - RPMPsgInd2Pro[J];

if ( BlendRatio[3]* MRQPsgInd3Pro[J]/100) > (TMRPPsg[3] *
PsgPctInd3Pro[J]/100)
then RPMPsgInd3Pro[J] := TMrpPsg[3] * PsgPctInd3Pro[J]/100
else RPMPsgInd3Pro[J] := BlendRatio[3] * MRQPsgInd3Pro[J]/100;
DMPsgInd3Pro[J] := (TMRPPsg[3] * PsgPctInd3Pro[J]/100 -
( BlendRatio[3]*MRQPsgInd3Pro[J]/100));
if DMPsgInd3Pro[J] < 0 then DMPsgInd3Pro[J] := 0;
IPPsgInd3Pro[J] := MRQPsgInd3Pro[J] - RPMPsgInd3Pro[J];

if ( BlendRatio[4]* MRQPsgInd4Pro[J]/100) > (TMRPPsg[4] *
PsgPctInd4Pro[J]/100)
then RPMPsgInd4Pro[J] := TMrpPsg[4] * PsgPctInd4Pro[J]/100
else RPMPsgInd4Pro[J] := BlendRatio[4] * MRQPsgInd4Pro[J]/100;
DMPsgInd4Pro[J] := (TMRPPsg[4] * PsgPctInd4Pro[J]/100 -
( BlendRatio[4]*MRQPsgInd4Pro[J]/100));
if DMPsgInd4Pro[J] < 0 then DMPsgInd4Pro[J] := 0;
IPPsgInd4Pro[J] := MRQPsgInd4Pro[J] - RPMPsgInd4Pro[J];
end;

for I :=1 to PIndN do
begin
for J :=1 to PProN do
begin
if I = 1 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd1Pro[J];
IPPsgInd[I] := IPPsgInd[I] + IPPsgInd1Pro[J];
end;
if I = 2 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd2Pro[J];
IPPsgInd[I] := IPPsgInd[I] + IPPsgInd2Pro[J];
end;

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```

if I = 3 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd3Pro[J];
IPPsgInd[I] := IPPsgInd[I] + IPPsgInd3Pro[J];
end;
if I = 4 then
begin
DMPsgInd[I] := DMPsgInd[I] + DMPsgInd4Pro[J];
IPPsgInd[I] := IPPsgInd[I] + IPPsgInd4Pro[J];
end;
end;
end;

for I:=1 to PIndN do
begin
IPPsg := IPPsg + IPPsgInd[I] ;
temp4 := temp4 + DMPsgInd[I];
temp5 := temp5 + TMRPPsg[I];
end;

( Calculations for EXTRACTION STAGE )
OPExtr := IPPsg ;
for I := 1 to EIndN do
begin
OPExtrInd[I] := OPExtr * ExtrPctInd[I]/ 100;
IPExtrInd[I] := OPExtrInd[I] / ( MrfExtrInd[I]/100);
IPExtr := IPExtr + IPExtrInd[I] ;
end;
end;

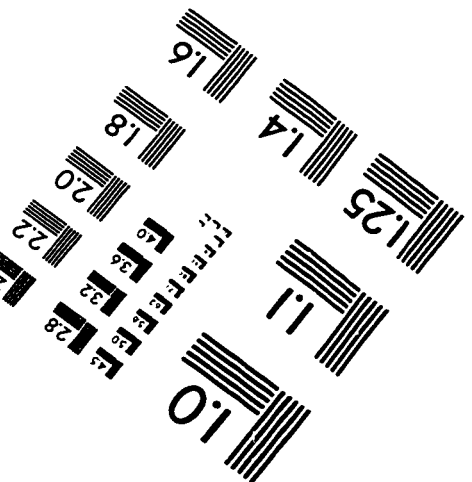
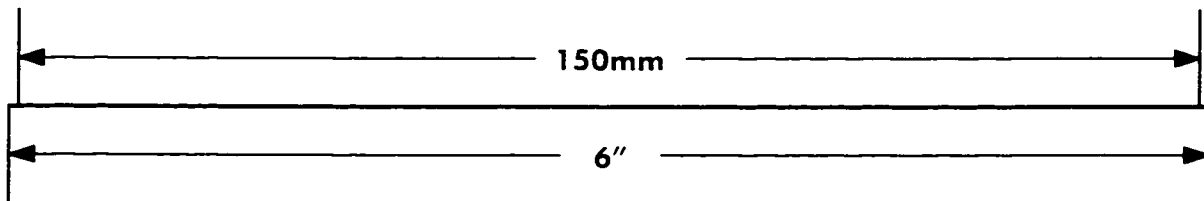
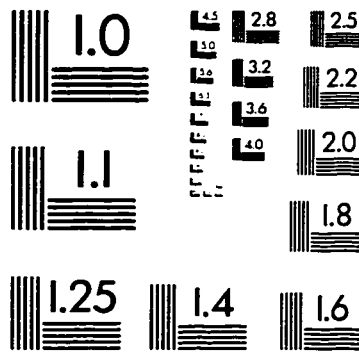
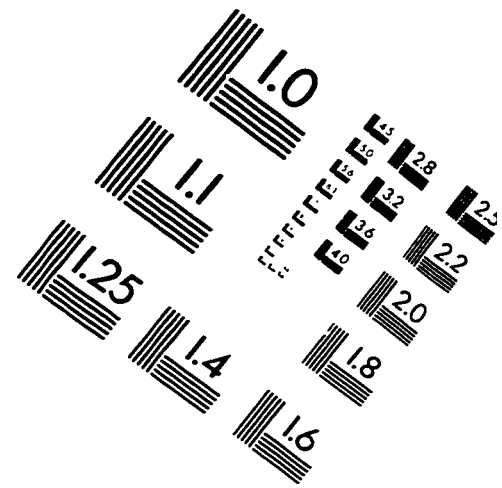
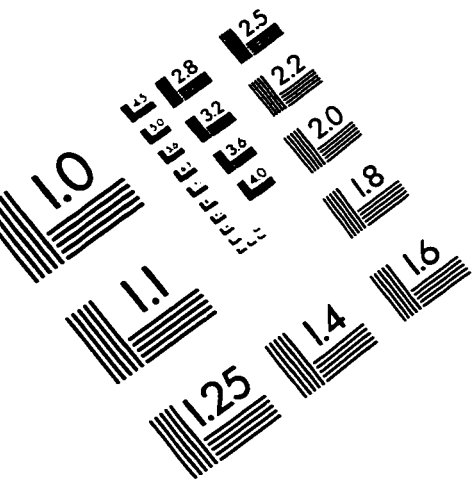
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## VITA AUCTORIS



Ramesh Majety was born in 1972 in Vijayawada, Andhra Pradesh, India. He graduated from Senior Secondary School in 1989. From there he went on to Aligarh Muslim University, India where he obtained a B.Sc Engineering in Electronics Engineering in 1993. He then went on to work for one and a half years in Hcl-Hewlett Packard Ltd., India till 1994. He is currently a candidate for the Master's degree in Industrial and Manufacturing Systems Engineering at the University of Windsor and hopes to graduate in Fall 1996.

# IMAGE EVALUATION TEST TARGET (QA-3)



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